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PART IV.

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THE

POPULAR CYCLOPÆDIA OF NATURAL SCIENCE.

By W. B. CARPENTER, M.D.,

AUTHOR OF "PRINCIPLES OF GENERAL AND COMPARATIVE PHYSIOLOGY," AND "PRINCIPLES OF HUMAN PHYSIOLOGY."

THE omission of the study of Natural Science from the course of instruction generally followed in this country, appears a neglect of one of the most important means of intellectual discipline and moral improvement which the Almighty has placed within our reach. This study, rightly pursued, has for its object to enable us to read with understanding in that bright volume of Creation, the pages of which are daily and hourly unrolled before us. To every one do "the Heavens declare the glory of God," whilst "the Earth" shows itself "full of His goodness;" but most of all to him who has learned to interpret the wonders they display; and to trace, in the glorious works by which he is surrounded, His power, wisdom, and love.

As a means of intellectual discipline, the study of Natural Science is perhaps second to none. Habits of accurate, discriminating, unprejudiced observation; of cautious reasoning, and of sound judgment; together with a fearless love of Truth, are cultivated by it. Moreover, it has the advantage of interesting the pupil much more than the greater part of the ordinary routine of instruction; and will tend to increase his desire for the attainment of valuable knowledge of any description. Further, at the present day, when Science is constantly furnishing some new and important improvement in those Arts which minister so much to our comfort, and in their turn contribute in various modes to the expansion of the intellect, the practical benefit of a general acquaintance with its principles is sufficiently evident. And whatever portion may be destitute of such direct application, will be found to have uses of its own, in furnishing subjects for the healthy occupation of the thoughts, and objects of pursuit as rational and interesting relaxation.

No works at present before the public appear to be altogether suitable to this purpose; the greater number of *strictly Elementary* Treatises on Natural Science being little else than abridgements of larger works; so that they are much behind the present state of science, and are for the most part but inaccurate copies of one another, executed in a mechanical spirit, and destitute of the striking novelties which scientific research is constantly bringing into view. The Publishers have therefore determined upon bringing out a connected series of Treatises upon the principal departments of Natural Science, designed and executed in accordance with the views above expressed. It is intended that these should all be *founded* upon such knowledge as every person of ordinary capacity possesses, and that the attention of the reader should be directed in the first instance to phenomena of constant occurrence around him; and it is hoped that by a judicious mode of treating the subject, principles may be gradually developed in such a manner as to render them fully comprehensible, and their more extended application thus marked out. "The neglecting to form a proper connection with previously-acquired knowledge; the undervaluing the results of

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OF

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PREFATORY NOTICE.

THE following little Work is intended to occupy a place somewhat intermediate between the simpler elementary treatises on Physical science, and the more elaborate works of a professedly philosophical character. With the former, it has this in common—that the Author has aimed at adapting it to those who have no preliminary knowledge of the subject; and to carry on his readers, step by step, from the known to the unknown, without requiring from them more than an accurate acquaintance with the ground over which they have already passed. To the latter, the Author ventures to hope it may be compared in this—that the highest principles of the science are introduced, and exhibited in their connexion with each other, and with the phenomena they govern. He has thus endeavoured to give his little work the character of a philosophical treatise; whilst, by the number of examples and illustrations which he has introduced, he has aimed at preventing what might have otherwise been its dry and abstruse appearance. In this attempt, he has merely followed out the plan which has proved successful in the former volume of the present Series.

The only preliminary knowledge required for the comprehension of the whole of this treatise, is an acquaintance with ordinary Arithmetic, and with the rudiments of Geometry. The mere beginner is recommended not to attempt to read the work straight through; but to omit Chapters V., VII., IX., and XII., until an accurate acquaintance has been formed with the rest; and not to proceed to the Astronomy, until a full acquaintance has been gained with the Mechanics.

The Author is well aware, that some parts of this Treatise may be deemed verbose and diffuse; and that the numerical illustrations may be thought to be too frequently introduced. To this he would simply reply, that some experience as a Teacher has convinced him of the necessity of explanations much more ample, and of illustrations much more complete, than those ordinarily given in elementary works; and that he has endeavoured to commit to paper the instructions which, when delivered verbally, were successful in impressing the minds of his pupils. The furtherance of this object has compelled him to extend the volume beyond the size originally contemplated, and it consequently becomes necessary to make a small addition to the price of the second Part.

In conclusion he would state, that, although a large part of the contents of this Treatise is the common property of all writers on the subject, many statements and illustrations may claim some degree of novelty. He thinks it right to add, that he is under particular obligation to the works of Professor Moseley, of King's College, London, for the assistance which he has derived from them in the first division of this volume; and to the Treatises of Sir J. Herschel, and Prof. Nichol, for a large part of the materials of the Astronomical portion of it.

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CHAPTER XIII.

OF HOROLOGY, OR THE CONSTRUCTION OF INSTRUMENTS FOR THE MEASUREMENT OF TIME.

391. The division of time into regular intervals was suggested, without doubt, to the first-created of the human race, by the movements of the heavenly bodies. From the time when Man was placed on the globe, and was taught by his Creator to express his thoughts in language, would he give one name to the space during which he received the genial warmth and light of the Sun, and another to the interval during which these were withdrawn from him. He would soon observe that the lengths of the day and night do not always remain equal; but that each increases up to a certain limit, and then decreases in a corresponding degree; and that, after this series of changes has been once gone through, it is repeated in precisely the same manner. He could not but notice a similar change in the degree of warmth received from the Sun, producing that variation in the seasons, which is so beautifully connected with the changing aspects of animated nature; and he would soon perceive that, although they come round with less apparent regularity,—each succession of seasons being more or less different in character from the last,—yet that summer and winter, seed-time and harvest, do follow in uninterrupted order, and that the recurrence of each corresponds with that of a certain length of day and night. Hence, by the return of these changes, the notion of a *year* was suggested to him; and we shall hereafter see, that, at a very early period in the history of the world, the length of the year was fixed with a tolerable approach to accuracy.

392. In like manner, the division of the year into months

was early suggested by the altering appearances of the Moon; and from the natural tendency which there is to divide into quarters, the idea of weeks may have arisen. But the week, consisting of seven days, was undoubtedly fixed by the Fourth Commandment, which ordained that one day out of every seven should be set apart for the worship of God.

393. It may be difficult, perhaps, to trace the origin of the division of the day into hours. When first adopted, however, it was not a division of the whole time between noon and noon (which is almost exactly the same in every part of the year) into twenty-four hours of equal length,—as with us at present; but a division of the day and night, whatever their respective lengths might be, each into twelve parts. Hence the time really included in the twelfth part, or hour, was continually varying; but the difference would not be so great in the country of the Greeks and Romans, or of the Jews, as in Britain; since there is not the same difference between the longest and shortest days, in warm countries, as in cold. The hours were at first measured only by a sun-dial; the principles of whose construction will be explained hereafter (Chap. XX.); but as this was useless during a half of each diurnal period, and frequently inefficient at other times, on account of the cloudiness of the weather, it became desirable to obtain some other means of measuring the exact lapse of time.

394. Various instruments were contrived, therefore, for this purpose; and some of them showed great ingenuity. The common hour-glass, in which the interval is measured by the passage of fine sand through a small hole, seems to have been one of the earliest of these. It cannot, however, be at all depended on for accuracy; since a difference of two or three minutes not unfrequently occurs in the times required by the sand to run through; and its passage may be very much hastened by frequently shaking the glass, so as to keep the surface of the sand constantly flat. The most satisfactory of the ancient instruments for the measurement of time, was the *Clepsydra* or water-clock; in which the hours were indicated by marks upon the side of a vessel filled with water, from whose bottom a small stream was allowed to flow out. As the water in the vessel ran off, its surface sank;

and its height, as shown by the marks, indicated the time that had elapsed. It was soon found, that the water does not run from such an orifice with a regular velocity; for, when the vessel is full, the pressure of the fluid is much greater than when it is nearly empty, and its flow will be proportionally faster. But by making the divisions on the side long or short, according to the rapidity of the flow, the hours might be equally divided. Various additions were made to these clepsydræ; especially by Ctesebius of Alexandria, who flourished more than 200 years before Christ. Thus the water was made to carry a float, which sank with it; and a string attached to this float, and carried round a wheel to which a hand or index was attached, caused this to revolve, and thus to point out the hours on a divided dial-plate. It is related in an old chronicle, that the Emperor Charlemagne received, as a present from the celebrated Sultan Haroun al Raschid, in the year 809, a curious clock, which struck the hours by means of little balls of metal let fall upon a bell, and in which figures of horsemen, at the hour of twelve, came forth through little doors and returned again. This is known to have been a clepsydra or water-clock.

395. The simplest mode of overcoming the difficulty, arising from the unequal flow of water through an orifice in the bottom of a vessel, is shown in the accompanying figure. This clepsydra consists of a cylinder of glass, furnished with a float *a*, which carries the syphon *b*. When this syphon has been once filled with water, the fluid will run out at the cock, *c*, until the whole water in the vessel has been drawn off *. The rate at which the water is discharged may be regulated by the cock, *c*; and as, by the connection of the syphon with the float, the mouth of the pipe is always at the same distance below the surface of the water, the quantity will always be the same, whatever be the height of the fluid in the vessel; and a scale, *d*,

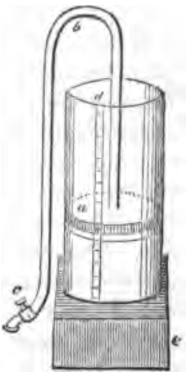

FIG. 121

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* See Vol. on HYDRAULICS.

on its side, divided into equal parts, will always indicate, by the place of the float, the lapse of equal intervals of time.

396. It appears that the use of the clepsydra was not known in England during the times of our Saxon ancestors; for we read in the history of Alfred the Great, that, in order to portion out his time exactly, into the periods which he allotted for his studies, meals, sleep, and the duties of his royal office, he had large candles made, with marks upon them, so that he might judge of the hour by the quantity that had burned. It was to prevent the errors occasioned by draughts of air, in palaces which were not constructed with nearly the same care in preventing them as is shown in our present ordinary dwellings, that Alfred contrived the first horn lantern.

397. All these instruments, however, were but rude attempts to effect that, which is at present accomplished far more perfectly by other means. By the combination of wheel-work, acting upon the principles already described under the title of the *Wheel and Axle* (Chap. X.), with the *Pendulum*, the laws of whose vibration have also been explained (Chap. IX.), clocks are now constructed, which indicate the passage of time with a degree of accuracy which it would have been formerly thought quite impossible to attain. It is to these instruments that the term *Clock* is now restricted. A watch is a portable instrument, in which the same mechanism is employed as in the clock, but in which, instead of a pendulum, there is a balance-wheel, whose vibrations are regulated by a delicate spring. Any clocks or watches might be termed chronometers or time-measurers; but this name is now appropriated to those which are constructed with the utmost attention to the perfection of every part, and with means for compensating certain errors to which they are liable. The most perfect clocks are those constructed for astronomical observations, in which the greatest possible accuracy is required; and hence these are ordinarily termed astronomical clocks. It must be borne in mind, however, that these differ from ordinary clocks in no essential particular;* though their appearance is often puzzling to those who see them for the first time, in consequence of the hour and minute-hands being fixed

on distinct centres, and pointing to different circles, instead of revolving about the same centre, and pointing to the same circle, as in ordinary clocks. Again, the most perfect watches are those constructed for the purposes of navigation, to which they give the most important assistance, as will be explained hereafter (§. 492); and these, being much larger than ordinary watches, though constructed on the same principle, are distinguished as marine chronometers.

It seems not inappropriate to introduce an account of these important instruments, between the chapters of this volume in which the principles of their construction are explained, and those in which their uses are unfolded.

General Principles.—Moving and Regulating Powers.

398. It has been stated (§. 275) that the object of clock-work is to maintain the oscillations of a pendulum, by continually communicating to it a slight additional impulse; and, at the same time, to register the number of these oscillations, so as to indicate the passage of time. In order to effect these purposes, a train of wheels and pinions is put in motion by a power acting on the first of them, whilst the last is connected with the pendulum by a peculiar contrivance, termed the *escapement.* In clocks which are to remain stationary, and in which a saving of room is no object, the moving power is a weight, which is suspended by a string coiled round a drum or barrel; this drum carries the first wheel of the clock, and imparts to the train the movement it derives from the gradual descent of the weight. If the whole of this force acted on the wheel-work alone, which it would do if the escapement were taken off, the weight would run down comparatively fast, and the train would be caused to move with great rapidity. But a part of it is expended in keeping up the vibrations of the pendulum; and the connexion of this with the wheel-work is such, that not a tooth of the latter can advance, unless permitted to do so by the swing of the pendulum. Hence a clock will not go, even when wound up, unless the pendulum be set in motion; but when its vibrations have once commenced, they will continue until the string has

been unwound from the barrel by the descent of the weight. In "winding up" the clock, we raise the weight by again coiling its string round the barrel; and thus communicate (as it were) to the machine, a power which will keep it in action for a certain limited time. It would not be difficult to extend that time, to any desired amount, by adding to the number of wheels. Ordinary watches, and the commonest kind of clocks, require to be wound up every day; chronometers for ships, and house-clocks, are commonly made to go without winding for a week; many clocks have been constructed, which only required winding once a month; and a few have been made to go for a year. It will be easily understood, upon the principle of the wheel-and-pinion (§. 339), that the greater the multiplication of velocity, the greater will be the sacrifice of power; so that, the longer a clock is made to go—or, in other words, the more slowly its weight is made to descend—the greater must be the power required to produce the same effect; and the weight must therefore be increased in the same proportion.

399. In small portable clocks, however, and in watches and chronometers, a weight cannot be thus employed; and motion is given to the wheel-work by means of a spring, made of elastic steel (§. 74) and coiled in a spiral. One end is secured to a fixed point; and the other, in the effort to uncoil itself, will carry round anything to which it may be attached. The spiral spring, partly uncoiled, is represented in Fig. 122. Now it is easy to understand, that a spiral spring, in uncoiling itself after having been tightly wound, exercises a much greater degree of force than it will do when it has become slackened; and therefore, if the spring were immediately connected with the wheel-work, the impulse which it would give to the train would be much greater at the beginning than at the end of the action. An attempt has been made, in France, to correct this inequality, by making a variation of strength in different parts of the spring itself, so that it shall unwind with equal force, whether it be tight or slack; and if this can be effected, the spring may be made to act at once upon the first

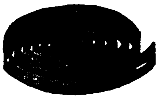

Fig. 122.

wheel of the train, as shown in Fig. 127; where O P is the spring, of which the outer end O is fixed, so that the inner end, being fixed on the axis or spindle of the wheel N, carries this round in its effort to uncoil itself. But it is found impossible to make such a correction with sufficient accuracy; and a different method is generally adopted.

400. The spring is enclosed within a hollow barrel or drum, to which its outer end is attached; and the inner or central end of the spring is attached to a fixed axle. Hence, when the spring has been coiled up, its elasticity will carry round the barrel, in its attempt to uncoil itself. The barrel, in turning round, pulls a chain, which was previously coiled round a conical axle, which is termed the *fusee*. This axle carries along with it the first wheel of the train. In winding up the watch, we coil the chain round the fusee, and draw it off from the barrel; by which action the spring within the barrel is coiled up and its power becomes very strong. In attempting to uncoil itself, it pulls the chain, which now acts upon the *small* part of the fusee. When it has gradually uncoiled itself, the power of the spring is weakened; but by this time nearly the whole of the chain is coiled upon the barrel, having been unwound from the fusee; and its pull or strain acts upon the *large* part of the fusee. Now upon the principles stated in the former part of the volume, the more distant the point, to which the force is applied, is from the central axis, the greater will be its power of giving the required motion. When the spring is acting most strongly, therefore, its power is applied at a far less mechanical advantage than when its power is nearly exhausted; and thus its action on the spindle of the fusee is equalized, so that from a variable power it is made to become nearly as regular, as that produced by the descent of a weight.

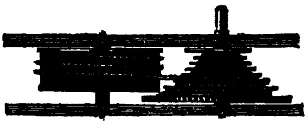

FIG. 123.

401. The contrivance by which, in winding up a clock or watch, we can turn the fusee without influencing the wheel-work, is shown in Fig 124. The first wheel is hollowed out to

receive the small *ratchet-wheel*, *d*, of which the teeth are so cut as to slant on one side, but to be upright in the other. In the same hollow, there is a movable click or *ratchet*, *b*, which is pressed down by the spring *c*. Now if the ratchet-wheel be turned in the direction of the slanting sides of its teeth (that is, from left to right in the accompanying figure), it will not carry the large wheel with it; for the ratchet will be lifted by the inclined side of each tooth, and will consequently pass over them all. But if the ratchet-wheel be made to turn in the contrary direction, it will carry the large wheel with it; for the upright side of the tooth will be caught by the ratchet; so that any force applied to the ratchet-wheel will act upon the ratchet, and consequently upon the large wheel with which it is connected. Now the fusee is attached to the ratchet-wheel; and hence, when the fusee is being drawn by the chain in the direction last mentioned, it carries round the large wheel with it, and gives motion to the whole train; whilst, if the fusee be turned in the contrary direction, as it is by the key in the act of winding, the teeth of the ratchet-wheel lift the ratchet, and there is no motion given to the large wheel. The same contrivance is applied in clocks, to the drum round which is coiled the string that suspends the weight.—In the better class of Time-keepers, whether clocks or watches, there is another contrivance introduced into the fusee, by which the train of wheels is kept in motion during the time when the weight or spring is being wound up; so that the inaccuracy that would be otherwise occasioned by the stoppage of the movement (which any one may observe, who notices the second-hand of an ordinary clock or watch, whilst it is being wound up) is prevented. This contrivance is termed the *Maintaining Power* or *Going-Fusee*.

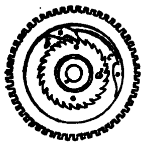
FIG. 124.

402. Having now considered the *moving* power, by which the train of wheels is kept in action, we shall examine the *regulating* power, by which its action is controlled. This, in all clocks now constructed, is the pendulum; whilst in watches and chronometers, it is a wheel termed the balance. The properties of the pendulum have been explained in a former part of the

volume, and need not be here repeated. The balance of a watch serves the same purpose as the pendulum, having the advantage of occupying much less space, and of acting equally well in almost any position. It consists of a wheel, having an axle which terminates in two very fine pivots, and so exactly balanced, as to be capable of being moved with a very small impulse in either direction. To the axle, however, is attached one end of a very delicate spiral spring; of which the other end is attached to the framework of the watch, as shown in Fig. 129. Now the action of this spring is like that of any other elastic body; it will produce a certain degree of resistance to any change of position of the balance; and the greater the alteration of its place, the greater will be the resistance, until at last the force which set the balance in motion is overcome by it, and the rotation ceases. But the spring has been so much displaced, that it tends to bring the balance back to its original position, with a gradually-increasing rapidity; and when it has arrived there, the force which it has acquired will carry it as far on the other side (§. 187). Again this force is resisted by the spring, and again will this bring back the balance to its former position.

403. Thus a balance, provided with a spring that possesses perfect elasticity, and uninfluenced either by friction or the resistance of the air, would go on vibrating backwards and forwards without cessation. But three retarding influences really act upon it;—want of perfect elasticity in the spring, so that each *reacting* force is somewhat less than the force which acted on it; friction of the pivots; and resistance of the air. Hence, in order to keep up these vibrations, it is necessary that a slight additional impulse should be continually given to the balance, as to the pendulum. When a balance is well constructed, its vibrations become almost perfectly *isochronous* (§. 265), whether the space through which it moves be long or short; hence it is not much affected by moderate differences in the strength of the impulses given to it by the moving power, and in this respect has even advantages over the pendulum. It is found advantageous to construct the balance-spring of the best chronometers, not in the form of a flat spiral, like that of the common watch,

shown in Fig. 129, but in that of a *helix*, or cork-screw, as shown in Fig. 125. And the balance itself is not a complete wheel, but is made in a peculiar form, which will be described hereafter (§. 432), for the purpose of compensating the influence of heat or cold upon the spring. The time occupied by each vibration of the balance, depends upon the strength of the spring—other things being supposed equal; and the strength is influenced by the length. A short spring, of equal thickness with a long one, is very much more elastic; hence by shortening the balance-spring, we increase its elastic force; whilst by lengthening it, we diminish that force. The greater the elastic force, the shorter will be the vibrations of the balance, and the less will be the time occupied by each of them; consequently the time-piece will gain when the spring is shortened, and will lose when its length is increased. It is by slightly altering the length of this spring, that a time-keeper is *regulated*, so as to go faster or slower than before.

Fig. 125.

404. The contrivance by which the pendulum or the balance is connected with the moving power, is termed the *Escapement*. The simplest form of this is represented in Fig. 126. Let x y be the axis on which the balance turns, or from which the pendulum is suspended; projecting from it in different directions are two leaves, c and d, which are termed *pallets*. At f b is seen a crown wheel, turning on a perpendicular axis o e; its teeth are cut like those of a saw; and the direction of its movement is from right to left,—that is, f moves towards b, whilst on the farther side, i moves towards a, and a comes gradually round to f. This wheel, termed the *balance-wheel*, is connected with the rest of the move-

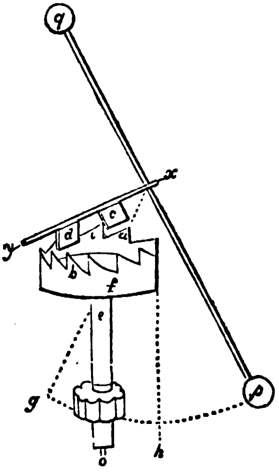

Fig. 126.

ment, by the pinion on its axis, as will be shown hereafter (§. 431). The pallets are so placed, with regard to the teeth of this wheel, that, as the axle turns from one side to the other by the swinging of the pendulum or the vibrations of the balance, the teeth are permitted to *escape* alternately from each of them, and thus the wheel turns round with an interrupted motion. In the figure, the pendulum or balance is represented as at the extremity of its excursion towards the right; and the movement of the axis has just allowed the tooth *a* to *escape* from the pallet *c*; whilst at the same time, the tooth *b* is just about to fall on the pallet *d*. Now whilst the pendulum or balance is moving to the left, that is, from *p* to *g*, the tooth *b* still presses against the pallet *d*, and is prevented by it from moving further on, until the pallet has changed its position so far towards the left, as to allow the tooth to *escape* from it. During all the time that the tooth is pressing against the pallet, the balance-wheel is communicating to the pendulum or balance, through its means, a part of the power by which it is itself moved; and thus supplies the impulse required to keep its vibrations up to the proper extent. When the tooth *b* has escaped from *d*, the tooth *i*, on the other side of the wheel, will drop against the other pallet *c*; and will remain pressing against it, in like manner, until the return of the pendulum or balance to the position represented in the figure, lifts the pallet *c* sufficiently to allow the tooth *i* to escape from beneath it, as *a* had previously done. In this manner, then, the wheel is allowed to advance by an interval of half a tooth at each vibration of the pendulum or balance; and thus, if the wheel have 15 teeth, and the pendulum vibrate seconds, it will make one revolution in half a minute.*

405. This escapement was in use, long before either the pendulum or balance-spring was applied to the regulation of time-keepers. An account has been preserved, of a large turret-clock which was erected for Charles V. of France, surnamed the Wise, about the year 1370, by a German artist named Henry Vick. The mechanism of this clock differed very little from that of

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* A crown-wheel of this kind must always have an *odd* number of teeth; else the teeth on the opposite sides would come against the pallets at the same time.

later ones: it had the same crown-wheel and escapement as that just described; but instead of a balance or pendulum, the axis *x y* carried a cross bar, loaded with weights, like *p q*. It was so arranged that the axis *x y* was upright; and the cross-bar consequently horizontal. Here, therefore, the bar was moved backwards and forwards, solely by the action of the teeth of the crown-wheel upon the pallets of the axis. This was, of course, an extremely imperfect plan; and the *going* of such a clock must have been very inaccurate. But no essential improvement was made upon it, up to the middle of the 17th century; when the pendulum was first employed as a regulator. It has been mentioned (§. 257) that the laws regulating the vibration of the pendulum were discovered some years previously by Galileo. As he intended to adopt the profession of medicine, he first applied this principle to the measurement of the pulse; and he afterwards suggested the connexion of the pendulum with the clock. It is uncertain by whom this great improvement was first actually carried into effect. It is generally attributed to Huyghens, a learned Dutchman; but his claim has been disputed; and it has been asserted that the son of Galileo first applied the pendulum to a clock, which was constructed at Venice, about eight years previously to the date of Huyghens's invention.

406. The escapement first used to connect the pendulum with the clock, precisely resembled that which has been just described. The axis of the crown-wheel was vertical, as in Fig. 126; and the pendulum was attached to the horizontal axis *x y*. In fact, there was no essential variation from that representation, except that, instead of a cross-bar with weights, *p* and *q*, at either end, the lower portion only, *x p*, was left, to serve as a pendulum. It was found, however, that the extensive vibrations which a pendulum must make when so hung, were injurious to the regular going of the clock; and various contrivances have been devised to prevent this source of error, by constructing the escapement in such a manner, that the pendulum shall make shorter vibrations. These, of which the two most important will be hereafter described, (§. 417-21) have completely superseded the use of this original escapement (termed the *crown-*

wheel and *verge*) in clock-work; but it is still used in watches, where, indeed, it is an object to make the vibrations of the balance as extensive as possible. All ordinary watches are constructed upon this plan; and they are distinguished as *vertical* watches, because the last crown-wheel has a vertical or upright position, as seen in Fig. 127.

407. The first watches that were made, were as imperfect as the early clocks; and differed only from them, in being made upon a smaller scale, and in the use of a spring instead of a weight, as the moving power. They had only an hour-hand; and most of them required winding twice a day. The invention of the spiral balance-spring followed the application of the pendulum to the clock, at no long interval; and thus both machines were made to receive the greatest possible improvement in the principles of their construction, at a very short interval. The honour of this invention is claimed by Huyghens, the Abbé Hautefeuille, a Frenchman, and our ingenious countryman, Dr. Hooke. There can be little doubt that it is really due to the last of these; for he was able to produce proof, that he had employed the balance-spring, and had applied for a patent for his invention, in the year 1658; whilst the claim of Huyghens was not made until 1674. No subsequent improvement of any great importance has been made in the construction of watches; except in regard to the escapement, of which the forms now considered the best will be described hereafter (§.426-9). Very great advances have been made, however, in the degree of perfection of the workmanship of these important machines; and it is difficult to imagine anything superior to those which are now manufactured.

Construction of Ordinary Watches and Clocks.

408. The general construction of an ordinary watch will now be explained. That of a clock is precisely the same, whether it be large or small; with the exception of the substitution of a weight and barrel, for the mainspring and fusee. On opening an ordinary watch case, we see that the wheel-work is for the most part contained between two round plates, which are connected

together by pillars. One of these plates is attached to the dial; but there is a thin space between them, which is occupied by the wheel-work that connects the motion of the hour and minute-hands. On the other plate is a raised portion, beneath which the balance works.

409. A general view of the work of a common watch, as seen from the side, is shown in Fig. 127. For convenience of display, the parts are all arranged in one line, instead of being disposed in a circle as they really are; and, in order to make them more distinguishable, the distance of the two plates, between which most of the work is contained, is much increased; as is also the space between the upper plate and the dial, which really lie close together. The *balance* is seen at A; and on its axis or spindle are the two *pallets*, *p*, *p*, which together constitute what is termed the *verge*. At C is seen the *balance-wheel*, the teeth of which resemble those of a saw; by the vibrations of the balance, the teeth of this wheel are permitted to escape from each of the pallets alternately, as already explained. On the axis of the balance-wheel is a pinion, *d*; which is driven round by the crown-wheel, K, (see §. 341): this wheel is termed by watchmakers the *contrate-wheel*. On the axis of this last, is a pinion, *c*, which works into the *third-wheel*, L; and the axis of the third wheel is another pinion, *b*, which works into the wheel M, termed the *centre-wheel* from its position in the centre of the

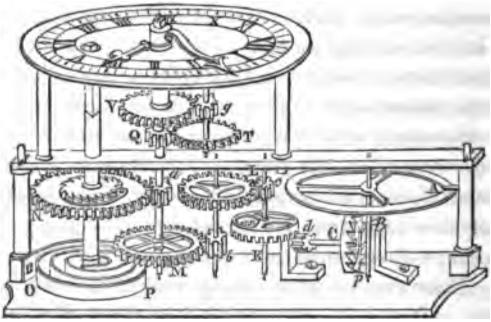

FIG. 127.

watch. (See Fig. 128, *e*). The axle of this wheel passes up through the centre of the dial, and carries the minute-hand; making one complete revolution in an hour. Upon this axle is placed the pinion *a*, which works in the *great-wheel*, N. This wheel is acted on by the main-spring; which is either fixed upon its own axis, as represented at O P in this figure; or is contained within a *barrel* or circular box, which acts by means of a chain upon the *fusee* which carries the great-wheel, as already explained (§. 400). Upon the axis of the centre-wheel, between the upper plate and the dial, is fixed the pinion Q; and this drives the wheel T. Upon the spindle of this wheel is a pinion *g*, which works into the wheel V. The axis of this last wheel is hollow, so as to allow the axis of the centre-wheel to pass up through it; and upon this hollow spindle the hour-hand is fixed.

410. It is seen, then, that in the watch, as in the clock, the moving power acts on a wheel which drives a pinion; that this pinion carries on its axis a wheel, which drives another pinion carrying another wheel,—and so on. Hence there is a continual increase of velocity, and at the same time a loss of power (§. 339). The revolution of the balance-wheel, *c*, is very rapid in proportion to that of the great-wheel, N; but its force is less in the same proportion; so that the slightest interruption (such as a thickening of the oil on the teeth and pivots) is sufficient to check the movement of the former; whilst the power of the latter, communicated to it by the spring, is sufficient to overcome a considerable resistance.

411. Many different trains may be adopted, to give the required proportions between the times of revolution of the several wheels; since their rates depend, not upon their *absolute* number of teeth, but upon the proportion between the teeth of the wheels and the leaves of the pinions. The centre-wheel must, of course, make one revolution in an hour; the balance-wheel is generally made to turn 9½ times in a minute; whilst the great-wheel makes one revolution in about four hours, so that, if the spring can turn it seven times round, the watch will go for 28 hours. The following is the *train* (or arrangement of the number of teeth in the wheels and pinions) usually adopted

in common watches. The *great-wheel*, N, has 48 teeth; and the pinion, *a*, into which it works, has 12 teeth; consequently this pinion will make 4 revolutions, whilst the wheel revolves once; and if the great-wheel turn round in 4 hours, the centre-wheel will make one revolution every hour. The *centre-wheel*, M, has 54 teeth; and the pinion *b*, has 6 leaves; so that it, together with the third-wheel, turns round 9 times, whilst the centre-wheel revolves once; and hence makes 9 revolutions in an hour. The *third-wheel*, L, has 48 teeth; and the pinion *c*, has 6 leaves; so that the velocity is again multiplied by 8; and the contrate-wheel, which is on the axis of the pinion, *c*, will make (8 × 9) 72 turns in an hour. The *contrate-wheel*, K, also has 48 teeth; and the pinion, *d*, into which it works, has 6 teeth; so that a further multiplication of velocity takes place, to the amount of 8 times; and the balance-wheel, C, which is carried round by the pinion *d*, turns (72 × 8) 576 times in an hour, or about 9½ times in a minute. The *balance-wheel*, C, has 15 teeth; and *half* of one of these *escapes* with every turn of the balance (§. 404); hence there are about (9½ × 15 × 2) 305 impulses given to the balance in a minute, so that each of its vibrations occupies 60-305th parts, or about 1-5th of a second.

412. It is often an object, however, to cause the fourth or contrate-wheel to revolve exactly once in a minute; so that its spindle may carry a hand which shall indicate seconds on the dial. This may be done by making the balance perform exactly 5 beats in a second; and by giving 15 teeth to the balance-wheel, 6 leaves to its pinion, and 60 teeth to the contrate-wheel. The contrate-wheel, in turning once round, causes the balance-wheel to revolve 10 times; and hence the number of escapes its teeth will make is (10 × 15 × 2) 300 in a minute, or one in every fifth part of a second. Or the balance may be adjusted to beat 9 times in 2 seconds; and then the number of teeth in the contrate-wheel must be 9 times that of the pinion it turns—that is, 54 to 6, or 63 to 7. Or the number of beats may be 4 in a second; and for this arrangement the contrate-wheel must have 8 times the number of teeth in the pinion it turns—that is, 48 to 6, or 54 to 7. When the contrate-wheel is to be thus made to turn 60

times in an hour, instead of 72 (as in the ordinary train), the number of teeth in the centre-wheel and third-wheel, and the number of leaves in the pinions they turn, must be regulated accordingly. The usual plan is to give the centre-wheel 64 teeth, and to the pinion it turns 8 leaves; so that this pinion, carrying with it the third-wheel, revolves 8 times for each turn of the centre-wheel. The third-wheel, having 60 teeth, works into a pinion of 8 leaves; and this last, carrying the contrate-wheel, turns 7½ times for each revolution of the third-wheel. Hence the contrate-wheel turns (8 × 7½) 60 times for each revolution of the centre-wheel; and as the latter makes one revolution in an hour, so does the former complete one in each minute.

413. The mode in which the parts of a watch are actually arranged, is shown in Fig. 128, representing the interior of a watch, from which one of the plates has been removed, seen from above. Here *a* is the barrel, containing the main-spring coiled within it; by the elasticity of this, the barrel is made gradually to wind upon itself the chain *b*, which was previously coiled around the fusee, and thus to give motion to that fusee, which carries round with it the great-wheel *c*. The pinion turned by the great-wheel is seen at *d*; and this carries on its axis the centre-wheel *e*. It is the spindle of this wheel which, prolonged through the dial, carries the minute-hand. The wheel *e* turns the pinion *f*, which carries round the third-wheel *g*; and this works into the pinion (which cannot be shown in this view) that carries round the contrate-wheel *h*. This wheel turns the pinion *i*, which carries round the balance-wheel *k*. The balance itself, and the verge, are supposed to have been removed with the upper plate, which is shown separately in Fig. 129. This gives a view of the back of the works of an

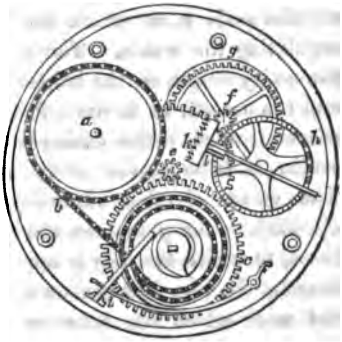

Fig. 128.

ordinary watch, as seen when the case is opened. The balance is seen at *p;* its spiral spring is shown by *s;* and the end of this is fixed at *t*. In order to regulate the length of this spring, so as to bring the vibrations of the balance precisely to their required number in a minute, there is a moveable piece, marked *o*, through a slit in which the balance-spring passes; this piece (which is termed the *curb*) can be made to travel towards one side or the other, by means of a wheel acted on by the circular scale *r*, to which the key is applied for the purpose of regulating the watch. The position of the curb *o* determines the *acting* length of the balance-spring, since the part between *o* and *t* is cut off, as it were, from the rest; hence, if the curb be moved towards *t*, the acting length of the spring is increased; whilst, if it be moved away from *t*, the spring is shortened. The effect of this alteration has been already explained (§. 403). At *q* is seen the square end of the spindle of the fusee, to which the key is applied for winding the chain off the barrel. In Fig. 130 is shown the work which lies between the dial and the plate on which it rests, having for its object to give motion to the hour-hand. The wheel *x* is turned by a pinion on the axis of the centre-wheel, concealed in this figure by the wheel *v*, but shown at Q in Fig. 127. The wheel *x* carries round with it the pinion *w*, which gives motion to the wheel *v;* and on the hollow

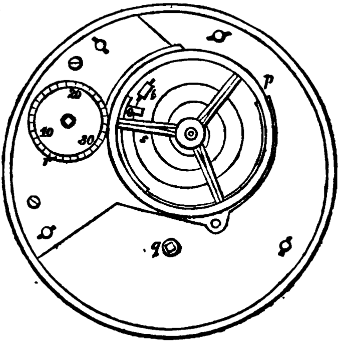

FIG. 129.

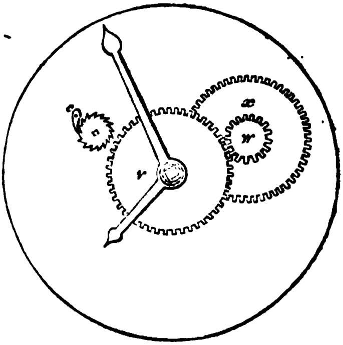

FIG. 130.

spindle of this last the hour-hand is fixed. The number of teeth in these wheels and pinions must be so proportioned, therefore, that the wheel *v* shall turn round with only 1-12th of the velocity of the central axis. Thus, suppose the centre pinion to have 15 teeth, and the wheel *x* to have 60 teeth, the latter will only revolve once whilst the former revolves 4 times. Again, if the pinion *w* have 20 teeth, and the wheel *v* have 60 teeth, the wheel *v* will turn round once whilst the pinion *w* revolves 3 times, and the central pinion (3 × 4) 12 times.

414. It is not exactly correct to say, however, that the central pinion and the minute-hand are *fixed* upon the spindle of the centre-wheel; for, if they were, the hands could not be moved without turning the centre-wheel, and we should not be able to *set* them, without disturbing the whole movement of the watch. There is a very simple provision for permitting this to be done. The pinion and minute-hand are fixed, not to the axis of the centre-wheel, but to a hollow spindle which is fitted upon this, and carried round by friction, so long as there is no opposing resistance. When we *set* the watch, however, the central axis remains unmoved, and we merely turn round the hollow spindle which carries the minute-hand and the pinion; this pinion acts upon the wheel *x*, which, through the pinion *w* and the wheel *v*, turns the hour-hand one-twelfth of the amount that the minute-hand has been moved; and thus the two are always made to turn conformably to each other, whether they be carried round by the going of the watch, or by the action of the key in setting it. If the face of any ordinary watch be examined, there will be seen a small round spindle projecting in the centre; this is the spindle of the centre-wheel. Enclosing this is the first hollow spindle, which carries the minute-hand, and which is squared at the top to receive the key; and this is again enclosed in a second hollow spindle, to which the hour hand is attached. These are seen in Fig. 127. Precisely the same means are adopted to connect the motion of the two hands in ordinary clocks; but where great accuracy is required, as in clocks used for astronomical observations, it is desirable to avoid unnecessary friction, as completely as possible. This is done by making the

hour-hand turn on a different centre from the minute-hand; and the former receives its motion from the latter, by means of a wheel containing 12 times as many teeth as the pinion which turns it, and therefore making its revolution in 12 times the period. In astronomical clocks, however, the hour-circle is not unfrequently divided into 24 parts, instead of 12; and the hand requires a whole day and night to traverse it. The object of this is to avoid any mistake, arising from the same numbers being repeated twice between noon and noon, or midnight and midnight. Some clocks have been constructed, especially at Venice, to strike all the numbers, from 1 to 24; but in this there can be no advantage.

415. The mechanism of an ordinary portable eight-day clock, is represented in Fig. 131. Of the two barrels, fusees, and trains of wheel-work here seen, the one on the right hand side alone has for its office the measurement of time. The other is called the *striking train;* and its office will be separately considered (§. 440). The works are arranged, as in the watch, between the plates, in which are holes for the pivots of the axles of the various wheels, &c. The front plate is attached to the dial, with an interval in which the hour-hand movement is contained, as in the watch; this interval also contains the mechanism by which the striking is regulated. The dial and the front plate are supposed to be here removed, so as to give an uninterrupted view of the train of wheels. The back plate is shown by the letters A B C D. The springs enclosed in the barrels E E give motion to the fusees F F, as in the watch, either by a chain or a piece of catgut. The main-wheel *a* of the going train, has 96 teeth; and this acts on the centre-wheel pinion, *k*, having 8 leaves.

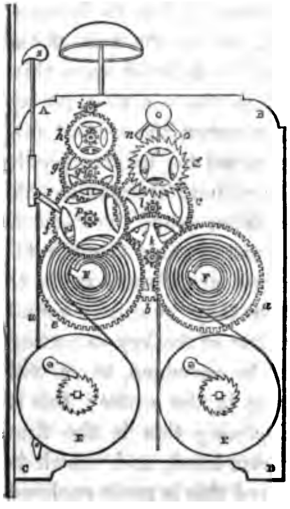

Fig. 131.

This pinion carries with it the centre-wheel *b*; and on the same spindle, as in the watch, the minute-hand is placed. The centre-wheel *b* acts on the pinion *l*; and this carries round with it the third-wheel *c*. This third-wheel, in its turn, acts on a pinion (not seen in the engraving) which carries round the scape-wheel *d*; and this wheel, acting on the pendulum by the pallets *n*, *o*, of the escapement, communicates to it the impulse received from the spring, whilst its own motion is entirely determined by the duration of the vibrations of the pendulum. For if, on the very same escapement, we were to hang a pendulum of 9¾ inches, another of 39 inches, and another of 13 feet, the duration of each beat—and consequently the interval between the *escape* of each tooth,—would be half a second in the first pendulum, a second in the next, and two seconds in the last.

416. The number of teeth in the wheels and pinions, therefore, must depend upon the length of the pendulum. Thus, for a pendulum vibrating seconds, the number of teeth in the scape-wheel is usually 30; since, as the wheel only advances to the amount of half a tooth at each *escape*, its revolution is then performed in a minute, and it may be made to carry a seconds-hand. If the centre-wheel and the third-wheel have 64 and 60 teeth respectively, and their pinions have 8 leaves, the multiplication of velocity will be (60 × 64 ÷ 8 × 8) exactly 60; so that the scape-wheel will turn round 60 times, for one revolution of the minute-hand. Where the pendulum vibrates half-seconds, however, it would be necessary to make the scape-wheel with 60 teeth, if it be required to perform but one revolution in a minute. Small portable clocks, however, such as those designed for a table or mantel-piece, are not made with a seconds-hand; and in these the scape-wheel is made with a small number of teeth, and revolves in a shorter time; the number of teeth in the wheels and pinions which connect it with the centre-wheel, being adjusted accordingly. In a clock now before the author, the centre-wheel has 84 teeth: this turns a pinion of 7 leaves, which must therefore revolve 12 times as fast, or once in every 5 minutes. This pinion carries round with it the third-wheel, which has 77 teeth in it; and the latter drives the scape-wheel by a pinion

of 7 leaves, so that a velocity of 11 to 1 is gained. The scape-wheel goes round, therefore, 11 times in 5 minutes, or once in somewhat less than half a minute. It has 32 teeth; and the pendulum, being not quite 8 inches long, allows each to escape in rather less than half a second.

Clock-Escapements.

417. The construction of the anchor-pallet escapement (so called from its having some resemblance to an anchor), which is now applied to nearly all ordinary clocks, is seen in Fig. 132. The scape-wheel has its teeth cut upon its edge, and not raised up as they are in the scape-wheel of a verge watch. The centre, from which the pendulum is suspended, is seen at A; and the same point is the centre of motion of the piece of metal A B C, which is termed the *crutch*, the extremities B and C being the pallets. This crutch is usually not fixed to the pendulum, since it is convenient to detach the latter, when the clock is to be moved from one place to another; but it is so connected with it, that, as the pendulum swings from side to side, the two ends of the crutch move up and down. The position of the crutch shown in the figure is that which corresponds with the direction A E of the pendulum. If the pendulum be carried to A F, the end B of the crutch would be raised still more; whilst if it swing to the other side A F′, the end B of the crutch would sink between

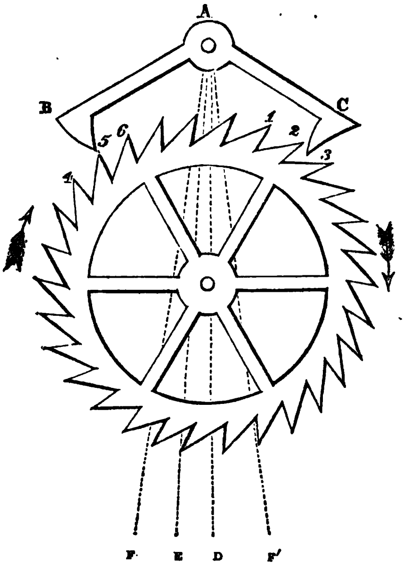

Fig. 132.

the teeth of the scape-wheel, whilst the end C would be raised quite clear of them. The scape-wheel is driven, by its pinion, in the direction of the arrows; but its motion suffers interruption by the alternate locking and disengagement of its teeth against the pallets of the crutch; and as the movements of these depend upon the pendulum, its time of vibration regulates the period in which the wheel revolves.

418. In the position of the escapement shown in the figure, the pendulum is to be supposed to be at E, and to be moving towards F. Now the elevation of the pallet B, against whose under side tooth 5 was previously pressing, has disengaged the point of that tooth; and the scape-wheel is consequently at liberty to move onwards. But it is prevented from doing so to more than the interval of half a tooth; for whilst the pallet B was being withdrawn from the space between 5 and 6, the pallet C was sinking into the interval between 2 and 3; consequently the wheel's revolution is checked by the fall of the point of tooth 2 against the upper surface of the pallet C. But as the pendulum continues to swing to F, the pallet C is still further lowered; and it gives a slight backward impulse to the tooth which was resting upon it, and consequently to the whole wheel. This backward movement, termed the *recoil*, may be seen in the seconds' hand of any common clock; this hand being attached to the scape-wheel, and carried round with it. Having completed its swing to F, the pendulum begins to move back again, and in doing so it is assisted by the pressure of tooth 2 against the upper surface of the pallet C. This pallet is gradually withdrawn from the tooth that rests upon it, so that this at last escapes. But in the meantime the pallet B has sunk into the interval between 5 and 4; so that when tooth 2 has escaped from the pallet C, tooth 4 drops against the under side of pallet B. The further motion of this pallet, which continues until the pendulum has reached the position F′, again causes the *recoil* of the wheel; but when the pendulum begins to swing back towards D, it is again assisted by the moving power of the wheel, which tends to make the tooth 4 (now resting on pallet B) press that pallet towards the left. When the pendulum has moved to E, tooth 4 escapes, as 5 had done before; and tooth 1 falls upon the pallet

B, as 2 previously did; tooth 5 having in the meantime moved on to 6, and tooth 2 to 3.

419. The objection to the recoil escapement consists chiefly in this;—that the impelling power of the weight, communicated through the train of wheels, is acting on the pendulum, by means of the inclined surfaces of the pallets, during the whole of each of its vibrations. Hence, any inequalities in the moving power are liable to produce a considerable effect on the pendulum, so as to vary its rate of vibration; and such inequalities are continually liable to occur from various causes. It was to avoid this source of error, that the *dead-beat* escapement was invented by Graham, a celebrated clock-maker at the commencement of the last century, to whom we owe also the invention of the mercurial pendulum (§ 423). The peculiarity of this escapement consists in the form of the pallets; the surface of each of which is partly a circle, having the point of suspension for its centre, and partly an inclined plane. The construction and action of this escapement are seen in Figs. 133 and 134. The centre of suspension is at A; whilst AB and AC are the two legs of the crutch, moving from side to side with the vibrations of the pendulum, whose line of direction is shown by AD. The scape-wheel moves in the direction shown by the arrow; and the position of the whole is seen to be such in Fig. 133, that the pendulum having nearly reached the limit of its vibration on the left hand, the tooth 6 has *escaped* from the pallet B, having just slid off the inclined portion of its surface, of which the dotted line, *b*, shows the direction. The tooth 2 now drops against the pallet *c*; and the further motion of the

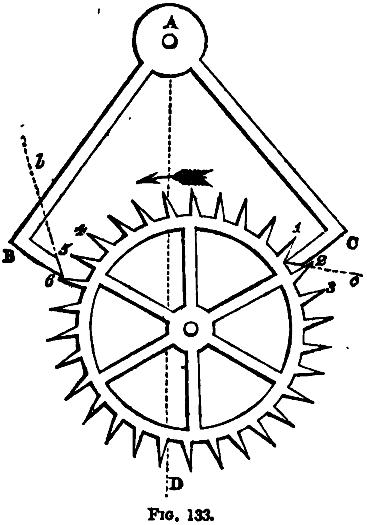

FIG. 133.

scape-wheel is thereby checked. The pendulum then begins to vibrate towards the right, carrying with it the crutch; so that the pallet B enters the interval between the teeth 5 and 6; whilst the pallet C is drawn out from the interval between 1 and 2. During this movement, however, the scape-wheel remains at rest; for so long as the tooth 2 bears upon the circular part of the pallet C, it does not either advance or recede; and its moving power is not communicated to the pendulum. But as soon as the pallet C has been sufficiently withdrawn, for the edge of the tooth 2 to press against the inclined plane, of which the dotted line *c* is a continuation, the wheel is allowed to move forwards; and it communicates an impulse to the pendulum, which aids it in its vibration towards D′, Fig. 134.

420. When the pallet C has been completely withdrawn by the continued motion of the pendulum, the tooth 2 is entirely disengaged from it; and the wheel would move onwards, but for the check it receives on the other side. Whilst the pallet C was being withdrawn, the pallet B was entering the interval between 5 and 6; consequently, just as the tooth 2 is disengaged from the former, tooth 5 falls upon the upper surface of the latter. This changed position is shown in Fig. 134. The pendulum, having completed its vibration towards the right, commences its return towards D (Fig. 133); and whilst it is moving in that direction, the tooth 5 remains at rest, and the whole wheel is consequently stationary, until the pallet B has been withdrawn far enough, for the tooth to rest against

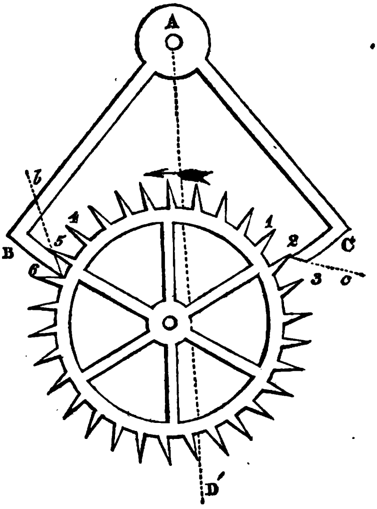

Fig. 134.

the inclined portion of its surface. When it does so, the wheel again begins to move onward, and gives the pendulum a fresh impulse, in a contrary direction to the first. When the pallet B shall have been completely withdrawn, and the pendulum have arrived at D, the tooth 5 will be disengaged, and will take up the position of the tooth 6 in Fig. 133.

421. Hence, during a large part of each vibration of the pendulum, the scape-wheel is stationary, in consequence of the resting of its teeth upon the circular portion of the pallets; and it is only whilst they are sliding down the inclined plane, which action occupies but a small proportion of the whole time, that the wheel moves on. Its movement, therefore, as indicated by the seconds'-hand, is a succession of jerks; very different from the recoiling movement of the scape-wheel of the ordinary clock. As the dead-beat escapement is the one now universally adopted in this country for the best kind of clocks, whether those designed for astronomical purposes, or for *regulators* of time (such as almost every watchmaker possesses), and also in many large public clocks, most of the readers of this description may obtain the opportunity of observing its action.

Compensation Pendulum.

422. Although every part of a clock may be constructed with the greatest perfection, its performance will be very inaccurate, unless it be provided with the means of compensating for those changes, which result from an alteration of temperature. It has already been explained (§. 269) that a very minute difference in the length of a pendulum, will produce a decided influence upon the rate of going of a clock. For if this alteration be so trifling, as to cause an increase or decrease of the time of each vibration by 1-1440th part of its whole length, it will occasion the clock to lose or gain a minute in every twenty-four hours,—a minute being the 1-1440th part of a day. The alteration in length, required to produce a difference of a second a day, will therefore be almost inconceivably small; and such as a trifling variation in the temperature of the air would be sufficient to produce. The amount will vary with the material employed. If the pen-

dulum-rod be of dry varnished deal, an alteration of the temperature to the amount of 10° (Fahr.) will only affect its going by one second a day. But if iron wire be employed, the alteration is three times as great; and it is increased to 5 seconds by employing brass. Hence, to insure the accurate going of a clock, some means must be devised to compensate for this source of error.

423. This compensation is ordinarily effected, in clocks constructed in this country, by the apparatus termed the *mercurial pendulum;* the form of which is shown in the accompanying figure. The rod of the pendulum consists of a flat piece of steel, which is formed at the bottom into a kind of stirrup, to carry a glass jar securely fixed to it. This jar is partly filled with mercury, which serves as the weight or bob of the pendulum. When a change of temperature causes the steel rod to expand downwards from its point of suspension, it also occasions an expansion of the mercury upwards from the bottom of the jar; and as the expansion of any given bulk of mercury is many times greater than that of the same bulk of steel, the rise of the mercury in the jar counteracts the lowering of the whole jar by the expansion of the rod; so that the place of the centre of oscillation remains the same, and the rate of vibration continues unaffected. The quantity of mercury requisite for the purpose can only be accurately determined by experiment; but in general it will be found, that the height of the column should be about 6·7 inches. If the column is not high enough, its expansion will not counteract that of the steel rod; if it be too high, the pendulum will be over-compensated, so that heat will cause it to gain, and cold to lose,—contrary to the usual rule. Of course what has been said of the mode in which the two expansions balance each other, equally applies to the contractions which will take place, in the steel rod and in the mercury, from the operation of cold. The absolute length of the pendulum is adjusted by a screw at D, by turning which the stirrup is raised or lowered upon

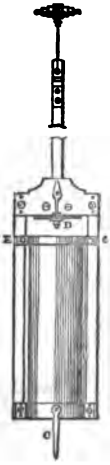

Fig. 135.

the rod. At C is a projecting index, which points to a circular scale below; by which the pendulum's arc of vibration may be observed from time to time.

424. A very simple compensation pendulum, which may be applied to any clock at the most trifling expense, consists of a wooden rod, dried and varnished; carrying at its lower end, by way of bob, a hollow leaden cylinder, which rests on a screw at the bottom of the rod. If the rod be made about 46 inches long, and the lead cylinder about 14 inches long, it will nearly vibrate in seconds (since the centre of oscillation will be at about the middle of the leaden cylinder, and therefore at about 7 inches from the end of the rod); and the expansion of the lead upwards is sufficient, or nearly so, to counteract that of the rod downwards. There is another very ingenious compensation pendulum, which was invented by Harrison, to whom we are so much indebted for his improvements in chronometers (§. 436). This, which is termed, from its form and aspect, the *gridiron* pendulum, is more used abroad than in this country. It is rather complex in its construction; and will be described in the treatise on HEAT. Many other contrivances have been devised for the same purpose; but they are not superior to these.

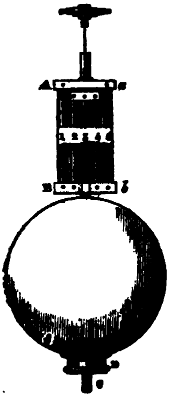

FIG. 136.

425. The regular going of a clock will partly depend also upon the steadiness with which it is fixed; and it is therefore desirable that a clock for scientific purposes should be as firmly supported as possible. After all, however, there is one source of error for which it does not seem easy to devise a remedy;—this is the varying density of the air, which will produce a variation in the resistance to the motion of the pendulum. When the air is dense, as shown by a rise of the mercury in the barometer, the resistance is increased, and the clock will go slower; the contrary result occurs, when the pressure of the air is diminished, as shown by a fall of the mercury. An attempt has been made to correct this error, by attaching small barome-

ters to the sides of the pendulum; it being intended that the rise of the mercury in the tube, by slightly raising the centre of oscillation, should counterbalance the effect of the increased resistance. This ingenious idea has not yet been properly applied to practice. To show the perfection at which clock-making has arrived, it may be mentioned that several clocks are now going, whose errors are less than 1-10th of a second daily.

Watch Escapements.

426. As in the Clock it is desirable to remove the Pendulum as much as possible from the *constant* influence of the moving power, so is it desirable in the Watch to withdraw the Balance from the same influence, slight variations of which (such as must be continually occurring from various causes) must otherwise greatly affect its regularity. In order to effect this, various kinds of escapements have been devised, which have completely superseded, for all but the most ordinary watches, the common verge-escapement already described (§. 404). In this escapement, as in the common recoil escapement of clocks, the teeth of the balance-wheel are continually pressing on the pallets, in such a manner as to be exercising a constant influence over the vibrations of the balance; and a fresh impulse is communicated at each vibration. In all the improved escapements referred to, the balance is so *detached* from the train of wheels, that it only receives a momentary impulse from the moving power; and in the intervals, the whole train of wheels is checked. In general this impulse is communicated only at every second vibration of the balance; that is, the balance, after receiving one impulse, completes its vibration in that direction, and returns to the same point again, before it receives the next.

427. One of the simplest contrivances by which these objects are fulfilled, is that known as the *duplex* escapement; the action of which will be easily comprehended by reference to the accompanying figure. AA represents the scape-wheel, which is provided with two sets of teeth;—1, 2, 3, &c., projecting from its sides, and termed the teeth of repose;—and *a*, *b*, *c*, &c., rising from the surface of the wheel, and termed the teeth of impulse.

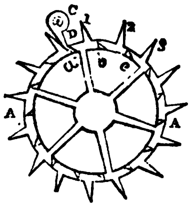

FIG. 137.

On the axle of the balance, there is fixed a piece CD, termed the impulse-pallet; this stands just above the surface of the scape-wheel, so that the teeth *a*, *b*, *c*, must strike the projecting portion D, when the wheel revolves. On the same axis, but placed a little below it, so as to be on the level of the teeth 1, 2, 3, &c., is a small roller made of ruby; this has a notch cut out of one side of it, as seen in the figure. The scape-wheel is constantly being urged, by its connexion with the going train, in the direction from 3 to 1; and consequently, in the position represented in the figure, the tooth *a* is just about to strike the impulse-pallet D. The impulse being given, the balance moves round, and the tooth *a* escapes from the pallet. The next tooth *b* does not immediately fall against it, however; since, before it can do so, the tooth 1 has been stopped against the ruby roller. There it is held, during the vibration of the balance and its return, until the roller comes back into the position shown in the figure, which will permit the point of the tooth 1 to pass by the notch; so that the tooth *b* may fall on the pallet D, and give the balance a renewed impulse just as its next vibration is commencing. Thus it is seen that the teeth *a b c* are those which give the impulses to the pallet; whilst by means of the check which, in the intervals, the points of the teeth 1, 2, 3 receive against the ruby roller, the train is kept in repose.

428. This escapement is not quite so commonly employed in this country, however, as the one known under the name of the *detached lever*. This essentially consists of the dead-beat escapement (§. 419), applied to the balance in such a manner, that a straight piece prolonged from the anchor or crutch, on the other side of its centre of motion, shall give a momentary impulse to a ruby roller fixed on the axle of the balance, each time that either of the pallets escapes.

429. Neither of these, however, is equal in perfection to that known, after the name of its inventor, as Earnshaw's detached

escapement. This is the one at present universally employed for chronometers and the most accurate timekeepers; and nothing but the delicacy of its construction, and its consequent expensiveness, prevents it from coming into general use. Its action will now be explained by the help of the accompanying figure. AA represents the scape-wheel, the teeth of which, 1, 2, 3, 4, &c., are considerably *undercut* on the side or face towards which they move. At BB is shown the steel roller or main pallet, which is fixed on the axle of the balance. This has a large notch cut in it; and the side of this notch nearest the tooth 1 is guarded by a thin plate of ruby, on which the points of the teeth strike as they pass it. The same arbor carries the small lifting-pallet *q*, which has a projection on one side, that lifts the end E *p* of the locking-lever or detent next to be described. This lever, EE, has its centre of motion at *c*, where it is attached by a screw to a stud S, which is firmly fixed to one of the plates of the chronometer. Near this stud, the lever is made thin and elastic; so that it has a springing power which keeps it pressing towards the scape-wheel, unless removed from that position. It is prevented from pressing too far, however, by the screw *d*, which is fixed into the stud D; for the head of this screw acts as a *stop* to the lever, and prevents it from moving further towards the right, than the place in which it is seen. At the other end of the lever is an extremely delicate spring *p*, which extends a little beyond the extremity of the detent. In the middle of the lever is the pin *o*, which serves to stop the teeth of the scape-wheel, when the detent is in the position represented in the figure, which is that of repose.

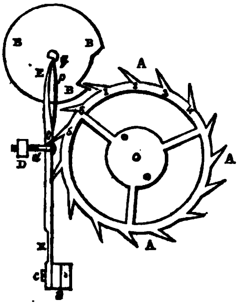

FIG. 138.

430. The following is the mode in which these parts act upon one another. The tooth 5 of the scape-wheel is seen to be resting against the pin *o*; whilst the tooth 1 is nearly ready to advance and strike the ruby face of the main-pallet BBB, but is prevented from doing so by this locking of the wheel. The

balance, however, being in motion from right to left (by the elasticity of its spring) carries round with it the lifting-pallet *q*, the projection on which acts against the end of the lifting-spring; and this spring, pressing against the end of the detent EE, raises it a little from its place, towards D, so as to withdraw the pin *o* from the point of the tooth 5. The wheel being thus unlocked, the tooth 1 strikes against the ruby face of the main-pallet, and gives the balance an impulse, which increases the extent of its vibration. Before the tooth has entirely escaped, however, from the ruby face, the lifting-pallet *q* has completely passed the point of the lifting-spring *p*; so that the detent is at liberty to fall back into its place, which it is caused to do by the spring at its fixed end. Hence, by the time that the tooth 1 has escaped from the main-pallet, the pin *o* will be in a position to check the next tooth, 6, which advances against it; and the whole train of wheels, therefore, again comes to repose. The balance, having completed its vibration forwards, begins to return, by the elasticity of its spiral spring. In this return, the lifting-pallet *q* has again to pass the end of the lifting-spring *p*; but it now merely separates this from the end of the detent, and does not move the detent itself. The locking of the scape-wheel still continues, therefore, until the balance has completed its return vibration, and again begins to move forwards; the lifting-pallet will then again raise the detent and set free the scape-wheel; the balance will receive a fresh impulse from the action of the teeth upon the ruby face of the main pallet; and the detent will again lock the wheel, as soon as the tooth has escaped. All this complex action, which occupies so long in the description, is really repeated in every half-second,—that being the time in which the balance is usually made to perform its double vibration.

Compensation Balance.

431. It is essential to the accurate going of a chronometer, that it should be furnished with some means of compensating the action of heat or cold upon the balance-spring, analogous to those by which compensation is made for the effect of change of temperature upon the pendulum. This is here also effected, by

taking advantage of the unequal expansion of different metals; so that the change produced in the length of the spring may be antagonized by a change in the form of the balance, producing a variation in the amount of force necessary to move it. From what has been formerly stated (Chap. X.) of the principles of the Lever, and Wheel and Axle, it is evident that, the nearer the chief weight of the balance is disposed to the centre of motion, the less amount of force will be required to turn it. Consequently if—when the action of heat upon the balance-spring has weakened it, by increasing its length—the same action can be made to cause the weight which the spring has to move, to approach nearer the centre, a perfect compensation may be effected. In the same manner, the spring being shortened by cold, and thereby rendered more powerful, the weight ought to be carried further from the centre, so as to require a greater moving power.

432. These objects are accomplished by the compensation balances represented in Figs. 139 and 140. The principle of both is the same; and the only difference consists in this, that the necessary weight is given in Fig. 139, by a single piece W on each arm of the balance; whilst in Fig. 140 it is distributed among the four screws, 1, 2, 3, 4, which are inserted into each arm. These balances are not made in the form of a complete wheel; but are composed of the cross-bar A B attached to the axis, and of the two circular arms carried by its ends. Each of these circular arms is a compound bar of brass and steel, the brass being on the outside. As brass expands by heat much more than steel, the effect of a rise of temperature is to cause the curvature of the bars to increase, so that their ends *a a* curl in, as it were, towards the cross piece A B, carrying inwards the

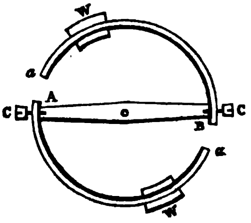

FIG. 139.

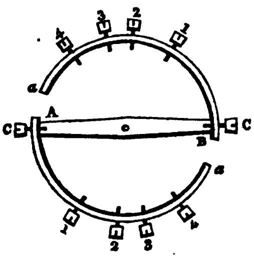

FIG. 140.

weights W W (Fig. 139), or the screws 1, 2, 3, 4 (Fig. 140); hence the balance will be more easily made to revolve, and the weakened action of the spring will be compensated. On the other hand, the effect of cold will be to make the brass contract more than the steel, and thus to diminish the curve of the circular bars, rendering them straighter; so as to increase the distance of the weights from the centre, and thereby to increase the power requisite to move them; thus counterbalancing the increased power given to the spring by its own contraction.

433. There is much difficulty in exactly adjusting this compensation to the error it is desired to correct. It may be that it is too great; in which case the chronometer will gain by heat and lose by cold. This is corrected by shifting the weights W W (Fig. 139) towards a part of the circular bars nearer to their attachment, so that they may be less influenced by the alteration of the curvature of the bars; and the same result is obtained, in the other form of the balance (Fig. 140) by drawing out the screws 4, 4, and screwing in 1, 1. On the other hand, if the compensation be not sufficient, the weights must be shifted towards the ends *a a* of the circular bars, so as to be more altered in place, when the curvature of the bars is changed by an alteration of temperature. The screws C C are obviously not affected by these changes of curvature, since they pass into the ends of the straight bar A B; but the effect of screwing them in or drawing them out, is to alter the rate at which the balance will vibrate; for if the moving power remain the same, and a portion of the weight be carried to a greater distance from the centre—as it is by partly drawing out the screws C C—the vibrations will be rendered slower; and the contrary effect will be produced by screwing them in. Now in finally adjusting a chronometer, it is found undesirable to alter the length of the balance-spring, after the point has once been ascertained at which its vibrations are isochronous or nearly so (§. 403). Hence, in order to bring it to the proper rate, it is found advantageous to make it go faster or slower as required, by slightly altering these screws, which are hence called, to distinguish them from the others, *mean time* screws.

Chronometers.

434. These are the principles on which the excellence of a time-keeper depends. In their application to practice, however, everything depends on the perfection with which the machine is constructed; and the minuteness of the conditions required for the good going of a chronometer may be judged of from the fact, with which practical men are familiar,—that, of two chronometers, constructed upon the same plan, and finished with equal care in all respects by the same hand, one may go very well, and the other comparatively badly, without any discoverable difference between them. In finally adjusting a chronometer, no attempt is made to keep it exactly to *mean time*; that is, to make it continue to point, day after day, and week after week, exactly to the correct hour; for it is just as advantageous to allow it to gain or to lose a few seconds a day, provided that the gain or loss be *regular* in its amount; since the real time may be known with equal accuracy from that which the chronometer indicates. Thus, suppose that I have a chronometer which was set 36 days ago, since which time it has been gaining 5 seconds a day; if its gain have been regular, its whole gain during that period will be (5 × 36) 180 seconds, or three minutes; and three minutes being deducted from the time to which the hands point, we shall have the real time. This regular amount of gain or loss is called the *rate* of a chronometer; and it is thus expressed:—When the chronometer is said to have a rate of + 2·53, we understand that it is gaining 2½ seconds per day; but if its rate is —3·2, we know that it is losing 3⅕ seconds per day. The more closely it keeps to this rate, the better the instrument will obviously be; but if it vary much from its rate, even though its errors should be sometimes on one side, and sometimes on the other, so as to compensate one another, and make the general average the same, the performance is bad, and cannot be relied on.

435. When the minuteness of the parts of a chronometer is considered, and the variety of disturbances to which it is exposed, the accurate performance to which it may be brought is most wonderful. For it must be remembered how very trifling

a cause, if constantly acting (such as a slight thickening of the oil), will greatly alter the result. Thus, as there are 1440 minutes in a day, any cause which makes each vibration of the balance (of which there are five in a common watch) take place in 1-7200th part less or more than its usual time, will cause the time-keeper to gain or lose a minute a day. And as there are 86,400 seconds a day, any cause which makes each vibration of the balance of a chronometer (which usually occurs 4 times in a second) take place in 1-432,000th part less or more than its usual time, will cause it to gain or lose a second a day—an error of very considerable magnitude. When it was first supposed that chronometers could be made sufficiently perfect to give important assistance in the determination of the longitude at sea (the mode of doing which will be explained hereafter), a parliamentary reward of £10,000 was offered in 1714 to any one who should construct a time-keeper capable of doing so within the limit of sixty geographical miles; £15,000, if to forty miles; and £20,000, if to thirty miles. Now a chronometer that has so much changed its rate as to have gained or lost, in a few weeks, two minutes more than it was estimated to have done, would gain the highest of these rewards; so that the utmost degree of accuracy which was contemplated as possible, at the beginning of the last century, when this act was passed, is far surpassed at present.

436. The reward was gained by John Harrison, who, in 1736, completed the first chronometer used at sea, after many years of patient study and laborious experiment. He gradually improved his machine; and in 1761, the first trial was made of it, according to the regulations of the Act of Parliament, by a voyage to Jamaica. In consideration of his advancing years, his son was allowed to take this voyage instead of himself. After eighteen days' navigation, the vessel was supposed by the captain to be 13° 50′ west of Portsmouth; but the watch giving 15° 19′, or a degree and a half more, was condemned as useless. Harrison maintained, however, that if Portland Island were correctly marked on the chart, it would be seen on the following day; and in this he persisted so strongly, that the captain was

induced to continue in the same course, and accordingly the island was discovered the next day at seven o'clock. This raised Harrison and his watch in the estimation of the crew; and their confidence was increased, by his correctly predicting the several islands as they were passed in the voyage to Jamaica. When he arrived at Port Royal, after a voyage of 81 days, the chronometer was found to be about 5 seconds too slow; and finally, on his return to Portsmouth, after a voyage of five months, it had kept time within about one minute and five seconds, which gives an error of about 18 miles. This amount was much within the limits prescribed by the Act; but Harrison did not receive the whole reward until a second voyage had been made; and large as the sum appears, it cannot be regarded as more than equivalent to the devotion of extraordinary talents, with unwearied perseverance, during 40 years, to the attainment of an object whose importance can scarcely be estimated too highly.

437. As an illustration of the improvements which have been since made in the construction of chronometers, the following circumstance, mentioned by Dr. Arnott* as having occurred to himself, is of great interest. "After several months spent at sea," he says, "in a long passage from South America to Asia, my pocket chronometer and others on board announced one morning that a certain point of land was then bearing north from the ship, at a distance of fifty miles; in an hour afterwards, when a mist had cleared away, the looker-out on the mast gave the joyous call of 'Land ahead!' verifying the report of the chronometers almost to one mile, after a voyage of thousands. It is allowable at such a moment, with the dangers and uncertainties of ancient navigation before the mind, to exult in contemplating what man has now achieved. Had the rate of the wonderful little instrument, in all that time, been quickened or slackened ever so slightly, its announcement would have been useless, or even worse;—but in the night and in the day, in storm and in calm, in heat and in cold, its steady beat went on, keeping exact account of the rolling of the earth and of the stars; and in the midst of the trackless waves which retain no

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* Physics, Vol. I. p. 87.

mark, it was always ready to tell its magic tale, indicating the very spot of the globe over which it had arrived."

438. It is surprising that, in spite of the great advantages resulting from the use of Chronometers in Navigation, many ships are sent to sea without them, even for long voyages. Not unfrequently must it occur, that the knowledge of the exact position of the ship, which may be obtained by the chronometer, produces a great saving of time, as well as contributes to the avoidance of danger. A remarkable instance of this was mentioned to the author, a few years since, as having just then occurred. Two ships were returning to London about the same time, after long voyages, one of them provided with chronometers, the latter destitute of them. The weather was hazy, and the winds baffling; so that no ship, whose position was uncertain, could be safely carried up the British Channel. Confident in his position, however, the captain of the first ship stood boldly onwards, and arrived safely in the Thames; whilst the other ship was still beating about in uncertainty near the entrance to the Channel. The first ship discharged her cargo, took in another, set sail on a fresh voyage, and actually, in running down the Channel, encountered the second ship still toilsomely making her way to her port!

439. Of the degree of accuracy which chronometers are capable of exhibiting, some idea may be formed from the following statement, kindly communicated to the author by a gentleman practically conversant with them. A chronometer made by Molyneux, had its daily rate determined, in August 1839, to be a loss of 7 seconds per day. It was then placed in a ship which traded to the coast of Africa, and was consequently exposed to great variations of temperature. Yet when again placed under careful observation, in November, 1840, (sixteen months afterwards) its daily loss had only changed to 6-7 seconds, being a difference of only 3-10ths of a second a day. As opportunities for ascertaining the real position of the ship, without chronometers, frequently occur at sea, any error in these may almost always be detected, before it has accumulated to any great extent; but even supposing that no such opportunity had

occurred for six months, and that the alteration of the rate had taken place at once, and had been entirely unknown, the whole error would have been under a minute of time, and consequently less than 15 miles of space. Another chronometer, constructed by Muston, which had made the same voyage, and been out about the same length of time, had its previous gaining rate of 1·9 seconds a day increased to 2·3 seconds; the difference being here 4-10ths of a second. It is customary for two or more chronometers to be carried by the same ship, that they may check one another; for if one alone were trusted to, an accidental irregularity in its going might lead to great error. The average of several,—their errors counterbalancing each other,—will be most likely to give the real time with great exactness.

Striking Apparatus.

440. The apparatus for striking the hour is somewhat complex; but we shall endeavour to make its action intelligible, as it is a very beautiful specimen of ingenious mechanism. The form which will be described is that which is adopted in the best English clocks: a simpler plan is adopted in the cheap German clocks, which are now so largely employed in this country; but they are very liable to get out of order. The difference consists, however, only in the apparatus by which the striking is regulated, as to time and number of strokes; the mechanism by which the hammer is made to strike the bell is the same in both cases. It consists of a train of wheels and pinions, put into action by the spring contained in the barrel E (Fig. 131) which turns the fusee F. The fusee carries round with it the main-wheel, *e*, which has 84 teeth; this drives the pinion *p*, of 8 leaves, which carries on its axle the *pin-wheel*, *f*, having 64 teeth. In the rim of this pin-wheel are 8 pins, which lift the hammer, *s*, by acting on its tail, *t*, when the train is in motion. The hammer being gradually lifted by each pin, is at last let go by it; and is made to strike the bell by the spring *u*. The pin-wheel drives a pinion, *q*, of 8 leaves, which carries round the *pallet-wheel*, *g*, of 56 teeth: as the pin-wheel has 64 teeth, it turns the pallet-wheel pinion 8 times for each revolution of its own, consequently this

pinion makes one revolution for every stroke of the hammer, an arrangement of which the use will be presently shown. The pallet-wheel acts on a pinion, *z*, of 7 leaves, on which is the warning-wheel, *h*, of 48 or 50 teeth; and this last turns the fly-pinion *i*. The object of this part of the train is only to equalize the motion; which is principally effected by the constant resistance of the air against the surface of the plate (termed the fly) which is whirled very rapidly round by the highest pinion. If it were not for this addition, the pin-wheel would move onwards with a jerk, after each pin had escaped from the tail of the hammer.

441. The striking train remains completely at rest during each hour's movement of the going train; and is only allowed to act at the conclusion of one hour and the commencement of the next. The mode in which it is restrained in the intervals, and its action at the proper time permitted and regulated, will now be explained. The mechanism by which this is effected is shown in Fig. 141. It is situated immediately behind the dial. The axis of the centre-wheel, as already mentioned, is prolonged through the dial, to bear the minute hand. In the striking clock, this also bears a small wheel, *a*, which gives motion to another wheel, *b*, of the same size and number of teeth; hence this wheel, like the former, revolves once in each hour. On the centre of this wheel is a pinion of 6 or 8 leaves, which turns a wheel, *c*, with a hollow axle, moving on the same centre as *a*, but at a different rate, as in the watch. This wheel has 12 times the number of teeth that the pinion contains; and therefore moves at only 1-12th of the rate. To it the hour-hand is affixed; and it also carries a peculiarly-shaped piece of metal, *d*, which is called the *snail*. The edge of this snail is cut into 12 steps, each of which is a twelfth of the circle of which it forms a part; but the distance of each from the centre increases regularly from 1 to

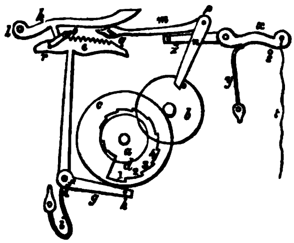

FIG. 141.

12. At *e* is seen a circular *rack*, fixed to the end of a bent lever, *e f g h*, whose centre of motion is at *f*. By the action of the bent spring *i*, this rack will be made to fall towards the left, when permitted to do so; but the amount to which it shall fall, is governed by the position of the snail, against the edge of which, the pin *h* will be brought to bear. This spring is prevented from forcing the rack out of the position shown in the figure, by means of the projecting piece on the lever *k*, which turns on the centre *l*, and drops by its own weight into the teeth of the rack. The form of these teeth is such, that when the rack is moved from left to right, the catch is lifted by them and allows them to pass; but, so long as it is allowed to drop between the teeth, it completely prevents the motion of the rack from right to left. The lever *k*, with its catch, may be lifted by the bent lever *m p n*, whose centre of motion is at *p*; and this is acted on by a pin in the circumference of the wheel *b*, which is seen in the figure, close against the tail of the lever.

442. Only one other part remains to be described—that which is known as the *gathering-pallet*. The axle of the pallet-wheel *g* (Fig. 131) projects through the front plate; and is furnished with a projection, seen at *o*, resembling one leaf of a pinion. This works into the teeth of the rack, in such a manner that, as the axle turns round, the rack is *gathered up* by it, to the amount of one tooth for each revolution. When the machinery is in the position shown in the figure—which it has during the whole time that the striking train is at rest—a projection on the gathering pallet rests on a pin which projects from the rack, as seen at *r*. It is this which keeps the striking train from acting; for, so long as this projection from the axle of the pallet-wheel bears upon the pin, so long must the pallet-wheel, and consequently the whole remainder of the striking train, be prevented from running on.

443. But when the time of striking is nearly come, the pin on the wheel *b* acts on the tail of the lever *n p m*; the end *q* of which raises the lever *k l*, and consequently lifts its catch out of the rack *o*, which is thus set free. The spring *i*, therefore, pressing upon the projection below *f*, causes the rack to fall

towards the left; and therefore sets free the projection on the gathering-pallet, by withdrawing the pin on which it rested. Hence the whole striking train would be set in action by its weight; if it were not that, at the same time that the gathering pallet is freed, another check is provided. The end *q* of the bent lever *m p n* bears a projecting piece, which, when the lever is raised, stops a pin placed on the circumference of the warning wheel *h* (Fig. 131). So long as the lever remains in this position, therefore, the striking train is prevented from acting. The amount of motion given to the rack is determined by the place of the snail. In the position represented in the figure, the pin *k* would be stopped by the second step; and thus the rack would only be permitted to move to the amount of two of its teeth. If the position of the hour-wheel were such, that the twelfth step of the snail corresponded with the end *h* of the rack-lever, then the pin would not be stopped so soon; and the rack would fall towards the left to the amount of twelve teeth. This preparatory action is usually made to take place about 3 or 5 minutes before the expiration of the hour; and it is called *giving warning.*

444. The machinery remains in this position, until the minute-hand points to XII; at which time, the wheel *b* has so far advanced, that its pin escapes from under the end of the lever, and thus allows it to fall, so that the end *q* no longer checks the pin on the warning wheel. The striking train is now set entirely free; the weight or spring that moves it produces a rapid revolution of its wheels; and the pins on the pin-wheel, acting on the tail of the hammer-lever, cause the successive strokes on the bell. This movement goes on, until it is checked by the action of the gathering-pallet on the rack. It has been already mentioned that the pallet-wheel, from the axle of which the gathering-pallet projects, turns round once for every stroke given to the hammer; and in each turn, it gathers up one tooth of the rack, causing it to move towards the right, so as to regain its original position. The projecting catch of the lever *k l* drops between the teeth at each advance, and prevents the rack from being moved back by the spring *i*. This goes on, until the rack has been completely brought back to its first position; and then the

projection on the gathering-pallet will be again checked by the pin *r*, and the striking train would be brought to rest.

445. It is evident, then, that the number of strokes will be determined by the number of revolutions which the gathering pallet is allowed to make; this depends upon the number of teeth on the rack which have to be gathered up by it; and this number is regulated by the extent to which the rack is permitted to fall, by the bearing of the pin *h* against the edge of the snail. It is almost impossible for any error to be committed by a movement so constructed; but the striking train of the common German clocks, now so largely imported into Britain, is regulated by an apparatus of simpler construction, which is very liable to give wrong indications. It principally consists of a large wheel (termed the *count-wheel*), usually placed at the back of the clock, on which are cut 78 teeth; this is so connected with the striking train, that it moves on one tooth for each stroke. The number 78 is the sum of all the strokes which the clock should make in 12 hours; consequently, after all these strokes have been made, the wheel returns to the same place again. From the surface of the wheel, near its edge, there projects a rim, in which are cut a series of notches, at intervals corresponding with the number of strokes. Thus, between the first and second notches, there is an interval amounting only to one tooth of the wheel; between the second and third notches, an interval of two teeth; and so on, up to the twelfth notch, the interval between which and the first is 12 teeth. The use of these notches is to receive a catch or projection, which keeps the striking train at rest during the hour, and regulates the number of strokes. When the clock gives warning, this catch is lifted out of the notch; but there is a temporary check applied to the warning wheel, as in the last case. When this check is removed, the train immediately begins to move, and continues in action until it is stopped by the falling of the catch into the succeeding notch. The number of strokes is determined, therefore, by the number of teeth which the count-wheel shall have moved on, before the catch falls into this notch,—or, in other words, by the number of teeth between each notch and the succeeding one.

446. The advantage of this last plan consists in its simplicity, and the facility with which the apparatus may be constructed. Its disadvantage consists in the readiness with which it may be put out of order. For it will be easily seen that if, from any cause, the clock be made to strike at an improper time, the count-wheel advances, and the number of strokes made will be one more than the last; so that, when it should next strike the hour, the number of strokes is one too many. Or if any cause (such as neglecting to wind up the weight of the striking train) should prevent the clock from striking at the proper time, the count-wheel remains stationary; and when the clock next strikes, it gives the number succeeding the one which it last struck which may, of course, be altogether wrong. On the other hand, in the more perfectly-constructed clock, the striking may be repeated any number of times within the hour, or it may be made to cease for a time altogether; and yet, when the clock next strikes the hour, it shall do it correctly. For the number of strokes, as just explained, is dependent upon the position of the snail; which is carried round by the hour-wheel, whether the clock strikes or not; and which must, therefore, always correspond with the place of the hour-hand. In some clocks of this construction, there is a simple contrivance for causing the hour to be struck at any time. This consists of a lever *x*, to one end of which the string *t* is attached, whilst the other carries a pin that raises the lever *m*. The action of this lever is checked by the two pins *s* and *z*, which prevent it from being moved too far in either direction. When the string *t* is pulled, the lever *m* is lifted, and all those changes take place, which have been described as occurring in the ordinary *warning* of the clock. When the string is let go, the lever is made to return to its place by the spring *y*; the lever *m* falls, the warning-wheel is released, and the proper number of strokes is made. Such a contrivance is convenient to those who desire to know the hour during the night.

447. Where a clock is made to strike the quarters, as well as the hours, a third train of wheels is required. The mechanism is the same in principle, with that which regulates the striking of the hours. The axle of the minute-hand carries round a snail

cut into four steps; and on a wheel corresponding to *b*, and revolving therefore in an hour, there are four pins, one of which lifts the lever that sets free the rack, every quarter of an hour. The rack has four teeth, corresponding with the four steps of the snail; and the passage of each tooth permits one stroke on the quarter-bell. Most frequently, the quarter-stroke is made upon two bells; and this is accomplished simply by having a set of pins on each side of the pin-wheel; of which one set acts on one lever, and the other set (acting a little afterwards, so that the two strokes may not be made at the same moment) on the other lever. In clocks constructed for purposes in which great accuracy is required, it is necessary to dispense altogether with the striking apparatus; since a certain degree of force is required to set it in action, that would derange the very regular movement of a delicate and perfect clock; in which the power of the weight ought to be no more than is requisite to keep the pendulum in action.

448. The same apparatus has been applied to watches; but, when made on so small a scale, and carried about in the pocket, its action is extremely liable to become deranged; and it is therefore of little use. The ordinary repeating-watches are made, not to strike the hours regularly, but merely to indicate them when desired to do so. In order to effect this, it is not requisite that the watch should be furnished with a second barrel and fusee with a distinct striking train of wheels; for it is easy to apply a power sufficient to produce the strokes, every time that the watch is applied to for this information. This is usually accomplished by pushing in the *pendant*, or projecting portion to which the chain is attached; and by this a spring is compressed, which sets in action the mechanism that produces the strokes. The number of strokes is regulated by a snail, resembling that employed in clocks. The ordinary repeating-watches are still very complex in their construction; and we prefer describing one, invented some years ago by Mr. Elliott of Clerkenwell, in which the number of parts is greatly reduced, by the combination of several into one. The striking portion of this watch is represented in Figs. 142 and 143. The most important part of

it is a flat ring or centreless wheel, of nearly the same diameter with the watch, supported in its place so as to admit of a circular motion, by four grooved pulleys round its external circumference. In Fig. 142, A B represents the plate to which the dial is attached; and the flat ring C D, with the rest of the striking mechanism, lies between this plate and the dial. The four pulleys are seen at E F G H. This ring has teeth cut in the part of the outer edge, *b*, nearest to the pendant; and the rack may be thus turned by the wheel *a*, to which motion is given by turning the pendant. At the lower part of this ring is a series of projecting pins; which in the position shown in Fig. 142, act upon the projecting pallet *i*; whilst in the position shown in Fig. 143, they act upon the pallet *r*. Of these, the former is destined to strike the hours, and the other the quarters. The internal edge of the ring is cut into two series of *steps*; of which the one seen on the left-hand side of each figure contains twelve, and regulates the striking of the hours; whilst the one on the right contains only four, and regulates the striking of the quarters. When the ring has had its position changed by turning the pendant, it is brought

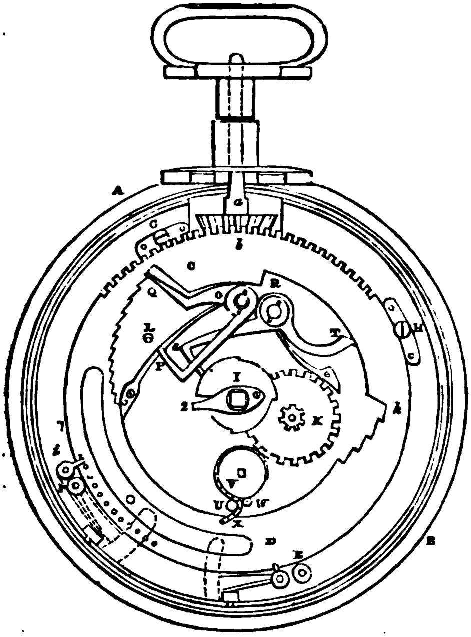

FIG. 142.

back again by a spring contained in the box or barrel V; the action of this spring is communicated to the ring by a chain which winds off the barrel, passes between the pulleys U and W, and is attached to the ring at X. Hence in whichever direction the ring is turned, the chain will be drawn off the barrel, and the spring put on the stretch, as seen in Fig. 143; and the elasticity of the spring will tend to bring back the ring to its previous position, shown in Fig. 142.

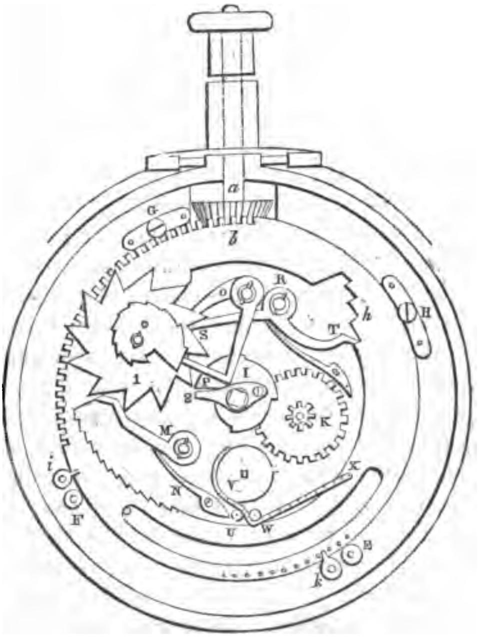

FIG. 143.

448*. The regulation of the number of strokes is effected by means of a snail, exactly resembling that of a clock. At I in either of the figures is seen the quarter-snail, placed on the axis of the minute-hand so as to revolve every hour, and cut into 4 steps. The same axle carries a projecting piece 2, which acts on the star-wheel 1, Fig. 143, in such a manner as to push it on to the amount of one-twelfth of a circle at each revolution of the minute-hand; consequently the whole star is made to turn once in the 12 hours. To this wheel is attached the hour-snail, as seen in Fig. 143; the common centre on which they turn is marked at L, Fig. 142. The hour-snail acts upon the bent lever P O Q, whose centre of motion is at O; and the end P is always kept against the step of the snail, by the spring seen in Fig. 142. In the position in which the lever is there shown, the snail having been removed, the end Q of the lever is pressing against the last or lowest step of the flat ring; and consequently the ring cannot be moved. But supposing the end P to be lifted by the snail to the 2nd, 3d, 4th, or any other step, the end Q will be raised to exactly the same amount, and will permit the ring to be turned from right to left, until it is stopped by the contact of Q with the corresponding step of the ring. In exactly the same manner, the quarter-snail acts upon the steps cut in the inner edge of the ring at *h*, by means of the bent lever S R T, whose centre is R.

449. Now when it is desired to ascertain the hour, the watch is held in one hand, and the pendant turned from right to left with the other. This causes a corresponding motion in the ring; and every pin, as it passes the pallet *i*, gives an impulse to the hammer, which causes a stroke upon the sounding body. The extent to which the ring may be turned, and consequently the number of pins allowed to pass the pallet, depends upon the position of the lever P O Q; and this, as just explained, is determined by the position of the snail. Hence the ring is stopped, just when as many pins have passed the pallet, as correspond with the step of the snail against which the end P of the lever is resting. After the hours have been struck, the ring is brought to its original position by the spring contained in the barrel V; and the pendant may then be turned in the opposite direction, so as to cause the other set of pins to act upon the pallet *k*, and to strike the quarters. Its motion in this direction is governed by the position of the lever S R T, of which the end S rests upon the quarter-snail, whilst the end T checks the steps cut in the ring at *h*. In the position represented in Fig. 143, the ring has been turned as far as possible in this direction; for the end S rests upon the highest step of the snail, and has lifted the end T so high, that the motion of the ring is not checked until it stops at the last step, by which time four pins have passed the pallet, and four strokes have been made.

ASTRONOMY.

CHAPTER XIV.

OF THE HEAVENLY BODIES IN GENERAL.—FORM AND DIMENSIONS OF THE EARTH.

450. The Science of Astronomy may be said to consist in the application of the laws, that have been described as governing the actions of bodies upon the surface of the Earth, to the explanation of the movements of the Heavenly bodies, and of their changes of appearance. It has been well observed by one of its most distinguished cultivators, that there is no science which, more than Astronomy, requires for its successful pursuit the complete dismissal of crude and hastily-adopted notions respecting the objects to be examined, and a corresponding readiness to admit any conclusion which is found to be supported by careful observation and sound argument, however adverse it may be to the opinions with which the mind was previously possessed, and even though it should seem opposed to the obvious teachings of common sense, and to the almost universal belief of mankind.

451. " Almost all the conclusions of Astronomy stand in open and striking contradiction with those of superficial and vulgar observation, and with what appears to every one, until he has observed and weighed the proofs to the contrary, the most positive evidence of his senses. Thus, the Earth on which he stands, and which has served for ages as the unshaken foundation of the firmest structures, either of art or nature, is divested by the Astronomer of its attribute of fixity, and conceived by him as turning swiftly on its centre, and at the same time moving onwards through space with great rapidity. The Sun and the Moon, which appear to untaught eyes as round bodies of no very considerable size, become enlarged in his imagination into vast globes,—the one approaching in magnitude to the earth itself,

the other immensely surpassing it. The Planets, which appear only as stars somewhat brighter than the rest, are to him spacious, elaborate, and habitable worlds; several of them vastly greater and far more curiously furnished than the earth he inhabits, as there are others less so. And the Stars themselves, properly so called, which to ordinary apprehension present only lucid sparks or brilliant atoms, are to him suns of various and transcendent glory—effulgent creatures of life and light to myriads of unseen worlds. So that when, after dilating his thoughts to comprehend the grandeur of those ideas his calculations have called up, and exhausting his imagination and the powers of his language to devise similes and metaphors illustrative of the immensity of the scale on which his universe is constructed, he shrinks back to his native sphere; he finds it, in comparison, a mere point; so lost—even in the minutest system to which it belongs—as to be invisible and unsuspected from some of its principal and remoter members. There is hardly any thing which sets in a stronger light the inherent power of truth over the mind of Man, when opposed by no motives of interest or passion, than the perfect readiness with which all these conclusions are assented to, as soon as their evidence is clearly apprehended, and the tenacious hold they acquire over our belief when once admitted *."

452. In a formal treatise on Astronomy, it may be proper to begin with the first principles of the science, which are no others than the laws of Motion and of Mutual Attraction, which have been stated and illustrated in the earlier part of this volume; and to carry out and apply these, so as to explain the movements and changing appearances of the heavenly bodies. Or, on the other hand, we might commence with the observed facts, and might bring them together in such a manner, as to make evident the real explanation of those facts; in each case avoiding all mention of the erroneous systems which have formerly prevailed, and which still have possession of the minds of the ignorant. It is, again, not an unfrequent or uninstructive mode of commencing, to give a history of these systems, showing how long

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* Sir J. Herschel's Treatise on Astronomy, p. 3.

it was before the truth was arrived at, and explaining the various steps by which it was attained. In the following chapters, an attempt will be made to combine these three methods,—each having its particular advantages. The principal appearances, which strike every person of common observation, will first be noticed; and the explanation which the ancient philosophers gave of these, corresponding as it does with what seem to be the deductions made from them by common-sense, will naturally follow. In the progress of time, however, more careful observation detected many circumstances which appeared inconsistent with this view; and after many attempts to make it conform to them, it was abandoned by the most intelligent seekers for truth in favour of another, which appeared at first sight less satisfactory, but which explains every principal phenomenon that could be discovered with the unaided eye, and even predicted some which were not actually witnessed, until the invention of the telescope afforded to Astronomy precisely the assistance of which it then stood in need. By carefully combining the observations which were made on these more correct ideas, and with improved means, and by sagaciously reasoning upon them, those high and general principles were arrived at by Kepler and Newton, which give to the Astronomy of the present time the character of such perfection and completeness.

453. When we take a survey of the heavens, without being interrupted in our view by any intervening obstacle, we see them spread out like a vast hemisphere, in the centre of which we stand; and this appears to join at its base the *horizon*, or boundary line of that part of the earth's surface which is visible to us. By day this immense vault is illuminated by a brilliant disk, which ascends from beneath the horizon in the regions of the east, gradually travels onwards with a continually ascending movement until it reaches the southern point, and then as gradually descends, until it sinks beneath the western horizon. The feeble twilight which it leaves behind is soon extinguished; and then appear from all sides in the immensity of space, a multitude of luminous points of various degrees of brightness, whose numbers augment as the darkness becomes more profound. These

bodies, like the sun, are found, by a little observation, to have regular and determinate motions. Some of them, like him, rise in the east, attain their greatest elevation in the sky as they pass the south, and sink beneath the horizon in the west. These are succeeded by others, which follow a similar course. All the stars, however, do not thus sink beneath the horizon; for there are some that never reach this circle, but are constantly above it. These also, however, perform a similar circuit; but there is one among them which appears immoveable; and the stars that are nearest to this (which is termed the Pole-star), have the least motion. Others, however, scarcely make their appearance above the horizon, sinking again almost as soon as they have risen.

454. Such are the general phenomena presented by the starry heavens. They are repeated every night, with a trifling variation. If the rising and setting of particular stars be noticed from the same place, it will be found that they appear and disappear a few minutes earlier each night; and if we accurately note the time when they pass any particular mark,—such, for instance, as the end of a wall, along which we look,—we shall see that the interval is about four minutes short of twenty-four hours. Now this difference between the *solar* and *sidereal* days,—that is, between the time which the sun requires to return to a certain point in the sky, and that which is occupied by a star,—is not enough to make any considerable change in the appearance of the heavens on two or three successive evenings; but the change becomes very perceptible, when we look at them after an interval of a month or two. For in 30 days, the difference amounts to (4 × 30) 120 minutes or two hours; so that we shall see the stars in the same position at midnight a month hence, as we should see them at two hours later to-night. In six months, the change would be so complete, that, if the darkness were sufficient to enable us to perceive them, we should see the same stars rising and setting at six o'clock in the evening, that we now see at six in the morning. And after twelve months, we shall find the place of the stars, at any given hour, exactly what it is at the same hour now; but if we had observed the number of times that any

star had risen or set, or crossed any mark, we should find that, instead of 365 times, corresponding to the rising and setting of the sun, it has been 366.

455. From the observation of these regular movements, it might be concluded that the whole starry firmament revolves from east to west, about the earth as a centre, in 23 hours; 56 minutes; and that the central line or axis of its revolution passes through the Pole-star. This was in fact the opinion of the ancients, who had no conception of the real sizes and distances of the heavenly bodies, but who regarded the stars as luminous spots, fixed to the interior of the celestial vault, and carried along with its revolutions. It was perceived, however, that the Sun must have an independent motion of his own; since his place among the stars was known to be constantly changing, by the difference in the height to which he rises, and in the consequent length of his stay above the horizon, as well as by the greater length of time that he requires to return to his line of highest elevation in the south. Still more evident was it, that the Moon must have an independent motion. For not only is there a difference in the time of her crossing any line in the skies, to the amount of nearly an hour in a day; but by watching her course in the heavens even for a short time, we can distinguish a manifest change in her place among the stars, some of these disappearing behind one edge of her disc, whilst others seem to start forth from beneath the other. Thus in a single month, she will have made one whole revolution less than the starry firmament. Hence the ancient Astronomers were led to attribute, both to the Sun and to the Moon, an independent motion round the earth, contrary in its direction to that of the stars; that of the sun carrying him once round our globe in a year; whilst that of the moon was much more rapid, and enabled her to complete her revolution in a month.

456. The Moon's place among the stars could be assigned by direct observation; but that of the Sun could not, since his brilliant lustre obscures all their paler fires. It could be ascertained, however, by a very simple process of observation; for as certain stars now pass the southern line or *meridian* at midnight,

these same stars will pass it six months hence at midday; and we may thus be certain of the sun's place among them at that time. On the other hand, we know the place of the sun at midday now, to be among those stars, which crossed the meridian at midnight exactly six months ago, and which will cross it again six months hence.

457. But the sun and moon are not the only celestial bodies which have a motion independent of that of the starry firmament. For the accurate observations of the Chaldean shepherds, who, as in later times, "kept watch over their flocks by night," appear to have early shown, that, whilst the greater part of the smaller luminaries retain exactly the same relative position towards each other, there are some (and two of these among the brightest of the whole) which are continually changing their places amongst the rest; sometimes approaching the sun, at others receding from him; sometimes moving directly onwards, at others appearing to move backwards; and yet, with all this apparent irregularity, repeating the same set of movements at regular intervals, some of which are of great length. These bodies were called *Planets* or *wandering* stars, to distinguish them from the *fixed* stars.

458. Sometimes there are to be observed in the heavens certain luminous bodies quite different in their appearance from those already mentioned, and undergoing changes of a far more remarkable character. When first seen, they are small and of little brilliancy; but they gradually increase in size and brightness, and at last appear like stars of large size, attended by a luminous train, which, from its occasional resemblance to a head of hair, has caused these bodies to be termed *Comets* *. These change their places among the fixed stars with greater and greater rapidity; they usually at last approach within a short distance of the sun; and after exhibiting their highest brilliancy, and the greatest extent of luminous train or tail, they gradually diminish in apparent size as they increase their distance from the sun and from us, and at last disappear wholly from our eyes. It is not surprising that these bodies should always have been

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* From a Greek word meaning *Hair*.

objects of popular wonder and curiosity; nor that their appearances, unrestrained as they appeared by any regular laws, should be regarded, by the superstitious, as portents of Divine wrath, and by the timid as betokening some terrific convulsion, which should produce the overthrow of our system.

> "Hast thou not seen the comet's flaming light?
> The illustrious stranger passing, terror sheds
> On gazing nations, from his fiery train
> Of length enormous; takes his ample round
> Through depths of ether; coasts unnumber'd worlds
> Of more than solar glory; doubles wide
> Heaven's mighty cape; and then revisits earth
> From the long travel of a thousand years."
>
> YOUNG.

Of the Earth's Form and Dimensions.

459. It was not unnatural that, with the limited amount of knowledge possessed by the earliest observers, as to the form of the Earth, and the variations in the aspect of the heavens occasioned by a change in their place upon its surface, they should have supposed it to be flat or nearly so; but more extended observation seems to have very early led to a tolerably correct estimate of its form. For those who lived on the sea-shore must have early noticed the phenomenon, which often excites surprise even now, in the minds of those who are ignorant of its cause,—of the disappearance beneath the horizon of the hull and lower masts of a receding vessel, whilst the upper masts and sails are yet distinctly visible,—or, on the contrary, the appearance of the upper masts and sails of an approaching vessel, some time before the hull comes into view. This can only be accounted for, by supposing that the sea has a curved surface, with which that of the land,—though interrupted by hills, valleys, and other irregularities,—must, of course, bear a general correspondence. Thus suppose that E A D be a portion of the earth's surface, and that an observer be situated at A, having the elevation B above it: his horizon, in the direction BD, will be limited by the line BD drawn to touch the curve at D, since it is evident that the portion of the surface below D will be invisible to him,

through the bulging or curvature at D. Hence if a vessel be sailing along the curve, she will be completely within sight until

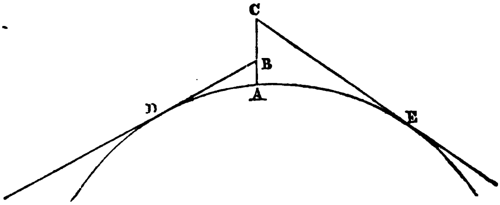

FIG. 144.

she reaches D, and after passing that point, her lower part will first sink beneath that line, whilst the upper portion will gradually follow, as she continues to increase her distance from the observer. Now this takes place at the same distance (provided the height of the observer be the same) in *any* direction, north, south, east, or west; so that we know that the boundary line of the horizon is, what it appears to be, a *circle*. Now on no kind of curved surface could this be the case, excepting upon one that is equally curved in *every* direction,—that is to say, upon a globe.

460. The extent of the horizon visible from any point, depends upon the height of the observer above the surface. This is evident from the inspection of Fig. 144; for if the observer be elevated to C, the point E, at which the line CE touches the surface, is more distant from A, than the point D, determined by the line BD, which is the limit of the view of the observer at B. A rough estimate of the Earth's magnitude may be formed from the knowledge of the distance of the visible horizon from the eye, at any particular level; for it is very easily proved by geometry, that the earth's diameter bears the same proportion to the distance of the visible horizon from the eye, as that distance does to the height of the eye above the sea-level. Now it appears by observation, that two points, each 10 feet above the surface, cease to be visible from each other, over still water, at a distance of about eight miles. As the interruption is caused by the convexity or bulging of the water half-way between them, we may

regard the horizon visible from either point as limited by a circle of 4 miles radius. The proportion will therefore stand thus;—as 10 feet : 4 miles (21,120 feet), so 4 miles = 8448 miles, which is not very far from the actual diameter of the earth, though somewhat too great. Taking 8,000 miles as (in round numbers) the actual diameter, we may estimate the proportion of the whole surface of the Earth, which can be seen from any elevation. The most lofty mountain known does not exceed 5 miles in perpendicular height,—a quantity which is no more than 1-1600th of the Earth's diameter, and therefore bears no larger a proportion to the whole globe, than the smallest grain of sand would do to a globe of 16 inches in diameter. By a simple rule of geometry, it is found that the proportion of the whole surface of the globe seen from any elevation, is almost exactly that which the height bears to the diameter of the Earth; so that from a height of 5 miles, supposing the view to be uninterrupted in any direction, no more than 1-1600th part of the Earth's surface would be visible. The proportion visible from the top of Etna, the Peak of Teneriffe, or Mowna Roa (in Owyhee), which are about two miles in height, is about 1-4000th.

461. The determination of the spherical form of the Earth, made by such observations as these, corresponds with that which was made, even by the ancient astronomers, from observations upon celestial phenomena. For it was early noticed by them, that the position of the Pole-Star, and consequently the height which all the other stars attain in the sky, is liable to variation, when the observer changes his place on the Earth's surface. This alteration is most evident in the case of the Pole-Star, which appears to a person travelling southward to descend gradually; and which seems to ascend, when the traveller directs his course towards it. This change is the necessary result of the change in the direction of the horizon, which is produced by the curved surface of the Earth. Did the observer move along a flat surface, the plane* of his horizon carried out into the starry sphere would always meet it in the same line; but as his own position

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* An imaginary flat surface, passing through the horizon, and spreading out in every direction.

on the sphere is changed, so is the direction of his horizon, and consequently the line in which the plane of that horizon will meet the starry sphere. Thus an observer at A (Fig. 145), would see the star *a* immediately above his head; the star *b* would be low down in the sky, and the star *d* would be invisible to him. But supposing that he changed his place to B, the star *b* is now above his head, the star *a* is low down on his horizon on one side, whilst the star *d* is seen just above it on the other. Again, he changes his place to D; the star *d* is then directly above his head, he loses sight altogether of *a*, and *b* is low down on his horizon on one side, whilst new stars come into view on the other.

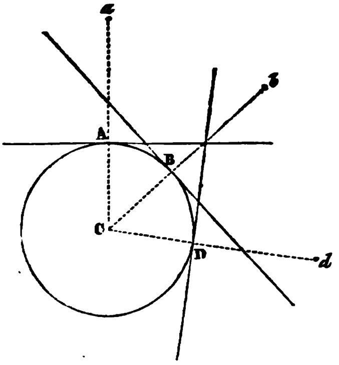

Fig. 145.

462. Now this change will take place whether he travel north, south, east, or west; but it becomes more evident in travelling in the northerly or southerly direction—and for this reason. It has been stated that the starry sphere appears to revolve round a fixed line or axis, which passes through the Pole-Star,—that star not undergoing any evident change in its position, during the whole daily revolution of the Heavens. Hence any change in *its* height above the horizon is more evident to us, than a change in any of the other stars, which are always varying their elevation in the sky. If the height of *any* of these be observed, however, when it crosses the meridian or southern line (where it attains its greatest elevation), it will be found to vary in precisely the same degree as that of the Pole-Star; but *they* will rise in the southern line whilst the Pole-Star descends in the northern. Thus, in the south of Europe, the brilliant constellation Orion, which with us never rises to any great height in the sky, passes completely overhead. The proportion of the whole starry sphere seen during its daily revolution, will thus vary in

different parts of the Earth's surface. The same is true of the Sun, when the alteration in his height, which takes place in the changing seasons, is allowed for. A person standing on the pole, and having the Pole-Star just above his head, will never see more than the northern half of the sphere; since the plane of his horizon will cut it at an equal distance between the two points round which it turns.

463. This may be made evident by a simple illustration. Hang up an orange or small globe by a string, in such a manner that it shall rotate round an axis passing through its centre. Then cut out of a sheet of paper a circular hole, just large enough to allow the orange to pass through, and hold this round the *equator* of the revolving globe,—that is, round that circle which is everywhere equally distant between its two poles, or the extremities of its axis. The paper will then represent the horizon of a person standing at either of the poles; and the portion above it will be that part of the sphere seen by an observer standing on the North Pole; whilst the portion beneath will be the part of the sphere seen by an observer at the South Pole. Now when the orange or globe is made to rotate, it will be seen that *the same* parts of the sphere are constantly above and below the horizon; and that there is no change in the height of any point upon it; so that an observer at the poles would always see the same stars, at the same heights in the heavens, and only changing their positions from east to west. The same would be the case in regard to the Sun, were it not that his height in the sky undergoes an alteration with the seasons. But when he is shining directly on the Earth's equator, he will be on the edge (as it were) of the polar horizon,—half above and half below; and will make a whole circuit in this manner.

464. On the other hand, let the position of the paper be so changed, that it shall still divide the surface into two equal halves, but that its plane shall pass through the axis of revolution, so as to touch on both sides the string or wire on which the globe is suspended. It will then represent the horizon of an observer on the Equator; being every-where equally distant from that spot on the orange, which rises the highest above it on

either side. Now the Pole-Star, which marks the northern end of the axis of the sphere, and the corresponding fixed point at the southern end of the axis (which is not marked by any visible star), are now on the horizon; and as the sphere revolves, *the whole* of it is seen to come progressively above the horizon, so that, in the diurnal revolution of the sphere, every star in it would be visible for 12 hours, if it were not obscured by the sun's light. Moreover, the Sun, when shining upon the Equator, instead of passing round the horizon, will describe an arch exactly over-head; but he will only be seen for twelve hours, instead of being visible, as at the Pole, during the whole twenty-four. *

465. On the other hand, the change in the apparent position of the stars, occasioned by travelling in an easterly or westerly direction, will not make any other difference than that which is being continually produced by a change of *time*. This will be evident on referring again to Fig. 145; for if we now suppose A B D to be three points on the earth's surface, of which A is east and D west of B, we perceive that a person travelling eastwards from B to A will perceive certain stars, which were previously beneath his eastern horizon, elevating themselves above it,—whilst others, which were previously near his western horizon, are seen to sink below it. But this very change would have taken place in a short time, if he had remained at B; so that, by journeying to A, he has merely anticipated them, by an amount of time that would suffice (in the diurnal revolution of the sphere) to carry the star *a* to *b*. On the other hand, if he travel westward to D, he loses sight of the eastern stars, whilst the western rise in the sky; and thus he delays, as it were, the rising of the former, and the setting of the latter. Precisely the same is the case in regard to the sun, which is seen to rise and set at A earlier than at B, and at B earlier than at D. Now where the sun and stars rise earlier and set earlier, they must

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* This illustration is better given by the ordinary celestial or terrestrial globe, where the horizon is marked by a wooden circle; but the simple device here proposed will answer the same purpose to such as have not the use of these instruments.

also pass the middle of their course or their greatest elevation, at an earlier hour; and, as we reckon our time at each place by the moment when the sun is on the meridian or southern line, which we call *noon* or twelve o'clock, it follows that there will be a difference of time in different places, according to their easterly or westerly direction,—the sun coming to his meridian earlier in the east, and later in the west; so that the clocks at A will be faster than those at B; whilst those at D will be slower.

466. By observation of the celestial bodies, then, we can determine our position upon the globe of the earth; and we can also measure, not only the distance from one place to another, but also the whole diameter of the earth, and even the difference between the Polar and Equatorial diameters (§. 480). In order to understand the manner of doing this, it is necessary to explain what is meant by the division of a circle into degrees, &c. Every circle, whether large or small, is considered as divided into 360 parts called *degrees*. The *absolute* length of the degree varies, of course, with the size of the circle; thus in the part *dc* of the circle *a b c d*, there are just as many degrees as there are in the part C D of the circle A B C D, or in the part C′ D′ in the circle A′ B′ C′ D′; but C D is equal to one-third *c d*, and C′ D′ is equal to seven times *c d*. But they all form the same proportion of their respective circles; for the entire inner circle is one-third the length of the middle circle, and one-seventh as long as the outer one. Hence

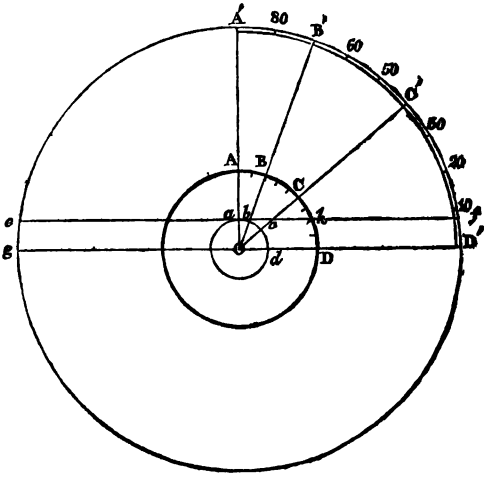

FIG. 146.

the angle between any two straight lines, as OC′ and OD′, contains the same number of degrees, whether those degrees are measured upon a large or a small circle; or, in other words, the line OC will cut off equal proportions of the several circles through which it is drawn. Thus, reckoning from D and D′, the portion cut off by the line OC′ is 40 degrees (40°); whilst that cut off by OB′ is 70°, and that by OA′ is 90°; and this is the same, whether measured upon the larger or the smaller circles. The degree is subdivided into 60 parts, which are termed *minutes;* and each of these is again divided into 60 parts which are called *seconds*. It is necessary to bear continually in mind the difference between minutes and seconds, as employed to express the division of the circle, and the division of time.

467. It is further necessary to explain the difference between the *visible* horizon and the *astronomical* horizon. The former has been explained to be the boundary of the prospect seen from any part of the earth's surface; and it might be supposed that, in order to ascertain the amount of the starry sphere which would be seen above this, nothing more would be necessary than to carry out a plane passing through this small boundary circle, until it should meet that sphere. And this is really the case; but it requires a little explanation to show, that a complete *half* of the vault of heaven is seen from any point of the earth's surface. For let the inner circle in Fig. 146 represent the earth; the boundary of the horizon, to a person at *a* is determined by the line *e f;* and this line does not cut off by any means half of the two outer circles, but a portion of each, which is less (on either side) than the whole, by a distance almost exactly equal to the radius O *a* of the earth. It is seen, however, that the *proportion* thus cut off from the larger half-circle is very much less than that which the smaller one loses, being only about 8°, whilst the latter is 22°.

468. Now, if we were to draw a circle at double the distance of A′ B′ C′ D′, the proportion of it that would be cut off by *e f* prolonged would be still less; and it would continually diminish, with the increase in the dimensions of the circle; so that the horizon of a person standing at *a* would come to be almost exactly

the same as if it were bounded by the line *g* D drawn through the centre of the earth, and parallel to *e f*. For the more distant the outer circle, the more insignificant do the small parts of it, *e g* and *f* D, come to be in proportion to the rest; and as a matter of fact, the nearest of the fixed stars is at a distance from the earth so immensely exceeding the radius O *a* of the earth, that the *cutting* off a ring of 4000 miles broad (as it were) from the lower edge of the hemisphere, does not make any sensible difference in its completeness; and the *astronomical* horizon at any place is *virtually* the same (in regard to the fixed stars at least) as if it were bounded, not by the line *e f*, but by the line *g* D drawn parallel to it, through the centre of the earth; and there are many reasons which make it convenient thus to determine it. In regard to the sun and planets, however, which seem to move in circles smaller than those of the fixed stars, the visible and astronomical horizons have a perceptible difference; and this is still further the case with regard to the moon, on account of her nearer proximity to the earth, which makes its radius (4000 miles) of some consequence in proportion to the circle in which she moves; so that her visible path is actually less than it would be if viewed from the earth's centre, by that quantity cut off from each extremity of it.

469. If, on the other hand, the observer be at any considerable height above the earth's surface, his horizon is extended to rather more than a hemisphere; so that to a person on the top of a hill, the sun does not set so early as it does to an observer on the level surface. The late celebrated aëronaut, Mr. Sadler, having once ascended in a balloon from Dublin, at about 2 o'clock in the afternoon, was wafted across the Channel, and approached the British coast as the sun was setting. His balloon was sinking too fast, however; so that he would have descended in the sea. To avoid this, he threw out his ballast, and suddenly sprung upwards to a great height. His horizon being thus extended to a larger portion of the sphere, the sun again came in sight above it; and he thus witnessed what might be termed a *western sunrise*. He subsequently descended in Wales, and thus witnessed a second sunset on the same evening.

470. In all measurements of the place of the heavenly bodies, it is necessary to make an allowance for the influence of our atmosphere in *refracting*, or bending from their regular straight course, the rays of light which proceed from them to us. This refraction does not take place (for reasons which will be explained in the Treatise on Optics) when the rays come from a body in the *zenith*,—that is, in the point of the starry sphere which is just over our heads, and which is therefore equally distant from the horizon on every side; and hence a body which occupies this spot is seen in its actual place. On the other hand, it very much changes the apparent place of a body seen in the horizon, making it seem higher than it really is; and the rays of all the heavenly bodies, which are situated between the zenith and the horizon, are more or less affected by it,—the more, when they are low down in the sky,—the less, as they are more elevated. Hence, the apparent descent of the sun, moon, and stars, below the horizon, is retarded; that is, these bodies are seen by us above the horizon, when a straight line drawn from our eyes through the visible horizon would find them below it. So much is this the case, that, when we see the lower edge of the sun or moon just resting (as it were) upon the horizon, the whole disk is really below it. Hence the duration of night and darkness is very perceptibly shortened by this influence. It would produce great errors in all calculations made from astronomical observations, if its amount were not exactly known and allowed for; but as it has been very correctly ascertained, for every degree of elevation which the body may have in the sky, there is no difficulty in making the necessary correction, by subtracting from the observed height a certain number of minutes and seconds, which is stated in the tables drawn up for the purpose.

471. We are now prepared to understand the general principles, upon which, by observation of the heavenly bodies, the relative places and distances of various spots upon the earth's surface may be exactly ascertained. It will be remembered that, to an observer at the north pole, the pole-star will appear in the zenith; whilst, by an observer at the equator, it is seen in the horizon. In travelling southwards from the pole, therefore, to any part of the equator, the pole-star will appear gradually to

descend in the sky. The height of the pole-star above the horizon, therefore, will correspond, for every place, to its distance from the equator. Now the whole distance from the zenith to any point of the horizon being a quarter of the entire circle of the starry sphere, or 90°,—and the distance of the pole from the equator being a quarter of the entire circle of the earth, and also 90°,—it follows that the number of degrees of elevation which the pole-star has above the horizon corresponds with the number of degrees which the particular spot, where the measurement is taken, is distant from the earth's equator. Thus in Fig. 146, supposing *a* to be one of the poles of the earth, and *d* a point on its equator, whilst *b* and *c* are two intermediate points on its surface, the pole-star will be seen from *a* in the zenith, or at 90° from the horizon, indicating that *a* is at 90° from the equator;—at *d* it will be seen *on* the horizon, or at 0°, indicating that the spot is at *no* distance from the earth's equator, or is *on* it; at *b* it will be seen at 70° above the horizon, and will thus indicate that the point *b* is at 70° from the equator;—whilst at *c*, being seen at 40° above the horizon, it will indicate that the distance of *c* from the equator is 40°.

472. A corresponding change will take place in the apparent positions of all the other heavenly bodies which we see on the *northern* side of us; but the contrary change will occur in the height of those on the *southern* side; for these will rise higher and higher in the sky as we travel from north to south. Thus, when the sun shines directly on the equator (which happens twice in every year,—see Chap. XX.), it will be seen by an observer there at the zenith, whilst to a person at either of the poles it will appear in the horizon. Hence, as the observer travels *northwards*, the sun will appear to descend; and he will consequently measure his distance from the equator, not by the sun's elevation above the horizon, but by its distance from the zenith. Thus to an observer at *c*, the sun will appear at noon (the time of his highest elevation), at 40° from the zenith,—or in other words, at 50° above the horizon;—whilst by an observer at *b*, it will be seen at 70° from the zenith, or at only 20° above the horizon. By ascertaining the sun's place at noon, therefore,

we can determine the distance of the place from the equator, which is termed its *latitude*, as well as by the observation of the height of the pole-star; and this is, on many accounts, the better plan to pursue.

472*. It is only on two days in the year, however, that the sun actually shines on the equator; for at all other times, its rays fall vertically upon a point either above or below it. Now supposing that it should be shining upon a point 20° above *d*, then it will be seen by observers at *c* and *b*, 20° higher in the sky than it would appear when shining on the equator; and to an observer at *a*, who previously saw the sun in the horizon, it will now appear 20° above it. This does not alter the real latitude of the place, however; and allowance must therefore be made, in calculating the latitude from the height of the sun, for this change in his position. Thus, in order to ascertain the latitude of the point *c*, we first ascertain the distance of the sun from the zenith at noon, which is now 20°; this gives us the distance of *c* from the point on which the sun is shining vertically; but as that point is itself 20° from the equator, we must add this 20° to the other, in order to express the distance of *c* from the equator, or its latitude. On the other hand, we will suppose that the sun is shining on a point 20° *below* the equator; it will then be altogether invisible at the *north* pole, and will appear to a person at the south pole to be 20° above the horizon; whilst at *b* and *c* it will appear to be 20° lower down in the sky than when it was shining on the equator, so that it will be on the horizon at *b*, and at an elevation of only 20° at *c*. Hence, as the *zenith-distance* of the sun, at either of these points, gives us the number of degrees which it is distant from the point whereon the sun is shining vertically, and this point is 20° south of the equator, we must *subtract* 20° from the observed zenith-distance, to find the true latitude of the place, or its distance from the equator.

473. The latitude of any place may thus be ascertained with the most perfect exactness, provided that we are precisely informed of the sun's *declination*,—that is, of the distance of the point on which the sun is shining, from the equator,—for each particular day. During the six months between the 20th of March

and the 23rd of September, the sun is vertical on some point *north* of the equator; its declination commencing with the 21st of March, goes on increasing until the 22nd of June, when it arrives at its highest amount, the sun being then vertical on a point 23½° (nearly) north of the equator. It then diminishes as gradually, until, on the 23rd of September, the sun again becomes vertical on the equator. The southern declination then begins, and reaches the same limit with the northern on the 21st of December; after which it begins to decrease, until the sun again becomes vertical on the equator on the 21st of March. Now the amount of declination may be calculated with great exactness, for each day in the year; and is specified in tables constructed for the purpose. Hence in determining the latitude of any place on land or at sea, nothing more is necessary than to take the sun's altitude at noon, by means of the instrument termed the quadrant, which will be immediately described;—this altitude is first corrected by subtracting the allowance which it is requisite to make for refraction (§. 470); it is then subtracted from 90°, which gives the sun's zenith distance; and this is corrected by *adding* the sun's declination for the day, if it be *north*, and *subtracting* it, if it be *south*. The result is the latitude of the place.

474. The determination of the altitude of the sun is effected by instruments of measurement, which are termed *quadrants*. The principle is the same in all, and the difference consists in the mode of applying it. Again referring to Fig. 146, let us suppose O *a b c d* to be a fourth part of a small circle of wood or pasteboard, divided into degrees and portions of degrees; and C′ to be the place of the body whose altitude is to be measured. In order to effect this, the lower edge O *d* of this quarter-circle must be directed to D, the horizon; the eye then observes from O the position of the sun or star at C′, and the line in which it is seen is marked on the divided edge of the quadrant. From the principles already stated respecting the division of the circle (§. 466), it is evident that the number of degrees in the arc *c a* cut off by the line O *c*, upon the circle *a b c d*, is precisely equivalent to the number in the arc C′ D′, cut off by the same line pro-

onged, from the circle A′B′C′D′; and thus the one is determined by the other. A large quadrant of this kind is employed in fixed observatories; but it is necessary to devise some other instrument of a portable kind, for the measurement of the altitudes of the heavenly bodies by the voyager or traveller.

475. The accompanying figure represents a quadrant adapted for this purpose. It consists of a frame BCDE, carrying the quarter-circle DE, which is divided into 90°; and of a moveable bar, AB, which turns on a pin at B that passes through the centre of the circle. At A and B are two *sights*, that is, upright pieces of brass, with a narrow slit, through which the eye of the observer looks at the horizon. At C is another upright piece of brass, termed the shade-vane; and the purpose of it is to cast a shadow, when turned towards the sun. In using this quadrant, the observer lays hold of the bar AB, and looks steadily through the sights A and B, at the line of the horizon; he then makes the quadrant turn upon the centre B, so as gradually to raise the shade-vane C, until the edge of the shadow thrown by it comes to correspond with the slit in the horizon-vane B. At this time, the line drawn through AB is directed to the horizon; whilst that drawn through B and C is directed towards the sun: the scale shows the angle between them, which is, of course, the sun's altitude. This instrument, however, is now but little used; the one which is termed Hadley's quadrant (after the name of the inventor) being preferred to it. In the latter, the sun's image falls upon a mirror which is fixed upon the bar AB; and this is turned, until his disk is

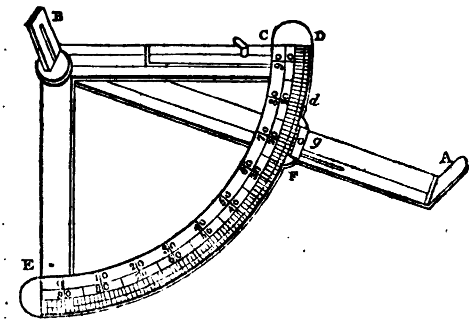

Fig. 147.

reflected to the eye, so as to coincide with the horizon. Now by a very simple law of optics, the reflected image will move a whole degree for every half degree that the mirror is turned; consequently half degrees on the scale measure whole degrees of the sun's elevation. The instrument employed for the simple measurement of the sun's altitude, therefore, need not be a quadrant, since a scale of 45°, or an eighth part of the circle, is sufficient to measure 90° in the heavens. Accordingly, *octants* (as they should properly be called, rather than *quadrants*) are sufficient for this purpose; but as they cannot measure any greater distance, they are now generally put aside for the *sextant*, an instrument constructed upon the same plan, which has a scale of 60° or one-sixth of the whole circle, and can therefore measure 120°,—a range which is necessary for taking distances between the sun and moon, or between the moon and stars, by which means the *longitude* is determined, as will be presently explained.

476. Now, it is by measurement of the actual distance between two points on the earth's surface, whose distance in degrees (that is, the proportion of their distance to the whole circumference of the earth,) is ascertained by astronomical observation, that we are enabled to determine the real dimensions of our globe. It is obvious that, as the poles are equally distant from every part of the equator, it is of no consequence along which of the circles that we may draw through the poles, crossing the equator (which are termed meridians), we make our measurement; since the degrees will have the same value or actual length in all. We shall presently find, however, that the length of the degree is different according as it is measured near the pole or the equator on any meridian; but taking its average amount at 69½ miles, which is very near the truth, we determine the whole circumference of the earth by simply multiplying this by 360, which gives as the product 25,020 miles. Supposing the earth to be a perfect sphere, its diameter might be readily calculated from its circumference, and would be found on this estimate to be about 7960 miles. But this is not the case; for, as already mentioned, the earth is an oblate spheroid, or a sphere flattened at the poles like an orange; which form has

been given to it by the operation of the centrifugal force, resulting from its movement on its axis, when its mass was in a soft condition (§§. 95, 215). Its real form and dimensions are ascertained by the comparison of the length of the degree in different parts of a meridian.

477. In making such measurements, it is of course desirable that as level a country as possible should be selected; and that the line measured should be in the exact direction of a meridian. But this is not absolutely necessary; for by the ordinary process of surveying, the distance between any two marked points,—as, for instance, a church-spire and a tower on a distant hill,—may be exactly determined in spite of intervening obstacles; and a similar process being carried on over a large extent of country, the distance, in a straight line, between any two points may be precisely ascertained, although the line of measurement has been continually varied in its direction, according to convenience. With such accuracy are these processes now conducted, that an error of 10 feet in the measurement of a degree would be regarded as a considerable one; and the error in fixing the distance of the two extreme points by astronomical observation can scarcely exceed (if proper care be employed) a single second. These errors may tend to correct each other; but supposing them both to tend the same way, so as to give a result greater or less than the truth, the whole amount of difference between the true diameter of the earth and the estimate thus formed, would not exceed about the third part of a mile; and this would be large allowance. It is not requisite to measure an *exact* degree; since the proportion of the part measured to the whole circumference is as readily determined, whether it be one, two, three, degrees, or any uneven quantity. The longer the portion measured, the less will be the probable error of the calculation from it. Thus, when an arc of 12½ degrees was measured by the French government, or the arc of nearly 16 degrees was measured in India by the British, the probable error would not be much more in amount, than that which would be incurred in measuring a single degree; and would be thus reduced, for each degree, to 1 part in 12½ in the former case, and 1 part in 16 in the latter.

478. Now the length of a degree of latitude,—that is, the measured distance between two points which are found by astronomical observation to be a degree apart from one another,—has been ascertained by measurement in Peru, where the lower end of the arc joined the equator, to be 362,808 feet. In India, at 16° from the equator, it is 363,044 feet, or 236 feet more. At the Cape of Good Hope, at 33° from the equator, it is 363,713 feet, or 905 feet more than in Peru. At Rome, in latitude 43°, it is 364,262 feet, or 1,454 feet more than at the equator. In England, in latitude $52\frac{1}{2}$°, it is 364,971 feet, or 2,163 feet more than at the equator. And in Lapland, in latitude $66\frac{1}{3}$°, it is 365,782 feet, being 2,974 feet, or nearly three-fifths of a mile longer than on the equator. It is thus seen, that the length of the degree increases with the latitude; and if a degree were measured still nearer the poles, the increase would be found to be much greater.

479. The mode in which this difference is produced by the peculiar form of the earth, may be explained without much difficulty. It has been shown, that the alteration in the horizon, and therefore in the height of the sun, of the pole-star, or of any other celestial luminary, above it, is due to the curvature of the earth's surface, producing a change in the direction of the observer's view. No such alteration would take place, if he travelled for any distance along a perfectly plane or level surface. Now, from the description of the form of the earth which has been already given,—that of a sphere flattened at the poles like an orange,—it is evident that its surface more nearly approaches to a level in the polar regions, than if the earth were a perfect sphere; whilst it is more curved in the equatorial region. Hence, an observer would have to travel further in the polar regions, to produce any given change in his astronomical horizon, and consequently, in the height of the stars, &c. above it; in other words, the length of the degree would be greater. But, at the equatorial regions, the curvature is more rapid, and the horizon is therefore altered much more by the same change of place; so that the stars will be raised or lowered a degree in the

sky, by a less alteration in the position of the observer;—in other words, the degree, as measured on the earth's surface, will be shorter.

480. By calculations founded on these measurements, it is found that the length of that diameter of the earth which joins the poles is about 7899 miles; whilst the length of any diameter joining two opposite points of the equator is 7925½ miles; so that the difference of the two diameters is 26½ miles. This estimate corresponds exactly with that which has been formed by comparison of the length of the seconds' pendulum in different places (§. 277).

481. When we have ascertained the *latitude* of a place, we have done something to determine its position on the earth's surface; but not nearly enough. We have only found out that it is at a certain number of degrees from the equator; and every point in a circle, drawn parallel to the equator, and at that number of degrees from it, will have the same latitude. Hence we not unfrequently speak of two or more places, whose climates we are comparing, as being under the *same parallel of latitude*; meaning that their latitude is the same, or that they are at the same distance from the equator. Now if we can specify the point of that circle at which the place of observation is, we determine its position on the globe; and it is described by the number of degrees which it may be east or west of a certain line drawn from the pole to the equator, and termed the *meridian* of any place through which it passes. Now the astronomers of all countries have agreed to make the equator the standard from which they reckon their latitude; but they have not made a similar agreement respecting the *meridian* from which they shall measure their eastward or westward distance, which is called their *longitude*. Thus British astronomers and navigators reckon from the meridian of Greenwich, as do in general those of the United States; but in France the meridian of Paris is regarded as the standard; whilst the Prussians reckon from that of Berlin; and the Germans from that of the island of Ferro, one of the Azores. The determination of the distance eastward or westward from the standard meridian,—or, in other words, of

the longitude,—is not effected with nearly the same facility as the determination of the latitude; for although the horizon, and the apparent places of the heavenly bodies, are as much altered by travelling eastwards or westwards, as they are by travelling northwards or southwards, yet they are only changed in the same manner as they would be by the simple lapse of a few minutes or hours, supposing the observer to remain at rest (§. 465); and therefore in all calculations made from observations of this kind, to ascertain the longitude, the knowledge of the *time* comes to be an essential element.

482. The general principle on which these calculations are made, is easily explained; it is only in applying it to practice, that any difficulty exists. The *time* of any place is determined by the sun's passage across the meridian, which in our northern hemisphere is the southern point; whilst in the southern hemisphere it is the northern point: at this point of his circuit, which is midway between the points of his rising and setting, he attains his greatest height in the sky. The moment when the centre of the sun's disc is on this line, is the hour of noon, or twelve o'clock; and the interval between one noon and another we divide into twenty-four hours. Now as the hour of noon is determined by the sun, all the other hours of the twenty-four, dating (as it were) from this, are also fixed by it. As the sun occupies twenty-four hours to make his whole circuit, and travels from east to west, it is obvious that he will make his first appearance, and will cross the meridian, an hour earlier at a place one-twenty-fourth part of the whole circumference, or 15°, to the east of us, than he does with ourselves; and therefore their whole time will be an hour *before* ours. On the other hand, he makes his first appearance to us, and crosses our meridian, an hour earlier than he does at a place 15° to the westward of us; and hence their time is an hour behind ours. Hence for every degree of longitude there is a difference of four minutes of time; the time being earlier when we go towards the east, and later when we journey to the west. A traveller leaving London and travelling westwards to Bristol, finds his watch, which was set correctly by London time, about 11 minutes too *fast* by that of

Bristol, their difference of longitude being nearly 3°. But, on the other hand, a traveller from Penzance, coming eastwards to Bristol, would find his watch 11 minutes too *slow* by Bristol time; Penzance being nearly 3° west of Bristol.

483. The time of any place is most correctly determined by means of the *Transit-Instrument;* by which the exact moment can be observed, when the sun, or any of the fixed stars, crosses the meridian. It consists of a telescope, supported in such a manner, that it can only move up and down in the plane of the meridian, having no horizontal movement whatever; and thus, at whatever height the body may be, whose *transit*, or passage across the meridian, is to be observed, the time when it does so may be known, by simply directing the telescope to the point at which we know that it ought to cross, and waiting until it shows itself exactly in the centre of the telescope. The general construction of the instrument is shown in the adjoining figure. The telescope, *e*, is firmly attached to a horizontal axis, *d*, made in the form of two cones, united in the middle, where it has to support the greatest pressure. The ends of this axis rest in the angle formed by two pieces shaped like a Y, of which one is supported on each side by the frame-work *b*, *c;* and this frame-work is attached to the circle *a*, through which pass the screws that fix the instrument to the place selected for it. When once fixed in such a manner that the telescope is always directed to some point in the meridian line, it must not

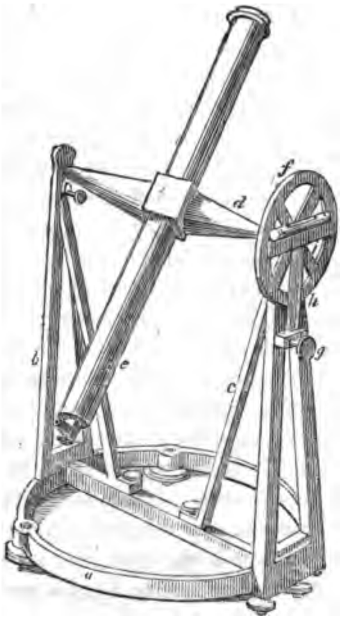

FIG. 148.
TRANSIT INSTRUMENT.

be moved. It is customary to set up a mark at some distance, by which it can be seen if the telescope is exactly in its place. One end of the axis carries a graduated circle, *f*, by which the telescope may be made to point exactly to the desired inclination on the meridian line.

484. The exact centre of the telescope is marked by a very fine thread, passing from top to bottom of the circular aperture through which we look; and there are also one, two, or more threads on each side of the central one, the use of which will presently appear. In making an observation of a transit, the observer adjusts the telescope to that point of the meridian at which he knows that the sun or a certain star will cross it; and being aware of almost the exact moment when it is to be expected, he takes his station at the telescope, and watches until it makes its appearance. An assistant then calls out the exact time by the clock, and goes on counting the seconds, until the observer sees the star or the edge of the sun touching the first wire; when he notes the exact time at which this happened. He then looks out for its contact with the second wire, and notes the time as before. The third wire will be the central one, if the instrument have five wires; and the observation of the passage of a star across this might seem to give all that was required. But it is very desirable not to trust to a single observation alone; and the multiplication of the wires is intended to permit a larger number of observations, so that their separate errors may check each other. After the star has passed the central wire, the observations are still carried on upon the times of its correspondence with the other two; and these times are accurately set down. An average of all the five observations is then taken in the following manner. The times of the 1st and 5th, and of the 2nd and 4th, are severally added together and their sums divided by 2; if the observations have been accurate, the result will be the same from each, and will correspond with that of the single observation upon the central wire. For the instrument is so constructed, that the 1st and 5th wires are at equal distances on the two sides of the central one; and the 2nd and 4th at half that distance.

485. Thus, supposing the distance of the wires to be such, that the sun, or a star, occupies 30 seconds in passing from each to the next, its contact with the 1st wire will take place a minute earlier than its arrival at the 3rd or central wire; and its contact with the 2nd wire will be 30 seconds earlier. On the other hand, its contact with the 4th wire will be 30 seconds later than its passage across the central wire; and its contact with the 5th wire will be a minute later. Thus supposing that the time when a star actually crosses the meridian is 35 minutes past 10 o'clock, the following will be the times when it will pass the several wires:—

	h.	m.	sec.		h.	m.	sec.		h.	m.	sec.		h.	m.	sec.		h.	m.	sec.
I.	10	34	0	II.	10	34	30	III.	10	35	0	IV.	10	35	30	V.	10	36	0

It is evident that, by adding together I and V, and also II and IV, and halving each sum, we shall obtain as the result 10 h. 35 min.; which corresponds exactly with the observation made upon the central wire. If this correspondence did not take place, however, there would be a slight error in one or more of the observations; and if it could not be found which was the faulty one, the error would be probably reduced by taking the mean or average of all of them. There is another advantage resulting from the power of thus making several distinct observations. It not unfrequently happens, especially in such a variable climate as ours, that the sun or star cannot be distinctly seen during the whole time that it is crossing the field of the telescope; and may, perhaps, be obscured just when it would be touching the central wire. Hence this observation might be altogether lost, if it were not for the aid gained from the rest. For if we know the time when the luminary touched the 1st and 2nd wires, and know that it would require two intervals of 30 seconds each, to pass on to the 3rd, we can calculate exactly the time when the third would be reached, even though we are prevented from seeing the contact. Thus we only lose one or two out of five observations; instead of losing our observation altogether. Of course, the observation of even one or two wires will be useful, when the rest cannot be seen; but the greater the number of contacts observed, the less chance will there be of error.

486. The mode in which such observations are employed, for the regulation of clocks and chronometers, may be very easily understood. If the tables calculated for the purpose give 5 minutes past 11 as the hour when a particular star crosses the meridian, and our clock stands at 6½ minutes after 11, at the moment when the star is seen on the central wire, we know that the clock is a minute and a half too fast. In the case of the sun, there would be equal or greater simplicity, if the earth moved round him at the same rate in every part of its orbit; for the clock ought then to point exactly to 12 o'clock each day, when his disc crosses the central wire of the transit instrument. But this, in consequence of the varying rate of the earth's motion, is not the case (§. 655); for, supposing the clock to keep accurate time, the sun would sometimes cross at a few minutes before 12, and sometimes at a few minutes after. As the amount of this difference, which is termed the Equation of time, is accurately known for every day in the year, it is easy to correct the clock from the sun's passage across the meridian, by adding or subtracting the number of minutes and seconds, that the clock ought to be faster or slower than the sun. Thus, if the sun pass the meridian at 3½ minutes before 12, by my clock, and I find in the Equation table that the sun is on that day 2 minutes faster than the clock, I know that the clock is 1½ minute too slow.

487. It is a remarkable circumstance, which has now been noticed in several instances,—that some persons see the passage of a star, or make any other similar observation, a considerable part of a second earlier than others. This singularity was first noticed by Dr. Maskelyne, who was Astronomer Royal in the latter part of the last century; for he found that his observations were constantly about 7-10ths of a second before those of his assistant. A still larger difference exists between two celebrated astronomers of the present day. It is not easily to be accounted for, since it is found to continue when the observers exchange places, and to be quite independent, therefore, of their instru-

ments. It might, however, be a cause of serious error in the comparison of longitudes, by means of transit observations; for if the observer at one place witness the transit at the exact time, and the observer at the other place do not see the transit until nearly a second after it has occurred, the distance of the former place from the latter will be wrongly estimated by that amount. The error may be prevented, by employing the same person to make the observations at both places; or by allowing for the tardiness of the observer, provided the exact amount of it can be ascertained.

488. Now, when the *exact time* at each of two places is known, the next step in the determination of the longitude,—that is, the distance of their two meridians, is to *compare* their times. Now, simple as this process appears, it is the one in which the greatest difficulty exists, when great accuracy is required. Nothing more would seem to be necessary, than to carry to one place a chronometer set to the time of the other, and to note the difference between the two; from which the difference of longitude may be easily calculated. Thus, suppose that a chronometer set to the time of one place, A, be carried to another place, B; and that A's time is found to be 16 minutes *faster* than B's; then, upon the principle already mentioned (§. 482), we know that A's longitude is (16 ÷ 4) 4 degrees *east* of B. On the other hand, suppose that A's time were found to be 22 minutes *slower* than B's, we should then know that A is (22 ÷ 4) 5½ degrees *west* of B. Nothing more than this would be requisite, if we could rely on the minute accuracy of the chronometers employed; and in fact, by using several timekeepers, and comparing the results of numerous observations, a very exact determination has been made of the difference in longitude of several places easily reached, from one another.

489. A second mode of comparing the times of two places, is to note the exact instant when the same phenomenon is seen at each. This phenomenon may be either terrestrial,—that is, an occurrence on the earth, such as the letting-off of a rocket;—or it may be celestial. The former method is of course restricted to short distances; but by establishing a chain of points of obser-

vation, and thus ascertaining the difference in longitude of each two, the relative longitudes of the extreme stations may be ascertained, by adding all these differences together. For instance, suppose that two observers on the watch at A and B, saw the firing of the rocket, the one at 20 min. 40 sec., and the other at 21 min. 20 sec., after 10 o'clock at night. The time at A is, therefore, 20 seconds earlier than at B; and as 4 minutes, or 240 seconds, are equivalent to a degree of longitude, the difference of longitude will be (240 ÷ 20) one-twelfth of a degree, or 5 minutes. Supposing that a rocket, sent up between B and the next station C, was seen at the former at 15 min. 20 sec. after 11 o'clock; and at the latter at 15 min. 44 sec.;—the difference of time between the two places is, therefore, 24 seconds, which is equivalent to (240 ÷ 24) one-tenth of a degree, or 6 minutes. The whole difference of longitude between A and C is therefore 11 minutes; and as A's time is earlier than C's, it is to the east of it. In this manner, the difference of longitude between the Observatories of Greenwich and Paris has been very accurately determined, notwithstanding the interruption of the Channel.

490. For the determination of the respective longitudes of distant places, however, it is more convenient to observe such celestial phenomena as are seen at the same moment from every part of the earth where they are visible. Such are the eclipses of the satellites or moons of the planet Jupiter; and the eclipses of our own moon. The latter afforded, previously to the invention of the telescope, the only astronomical means by which the longitude of distant places could be determined; but it is now completely put aside for other methods, which have the merit of greater accuracy, as well as of being more frequently available, —an eclipse of the moon being a comparatively rare occurrence. The eclipses of Jupiter's satellites were for a long time the chief phenomena by which the determination of longitude was accomplished. (§. 618.) The time at which these eclipses take place, —that is, when each moon is lost by passing into the shadow of Jupiter, or *immerges*, as also when it passes out of it, or *emerges* and becomes visible again,—can be precisely calculated before-

hand, and is set down by the time at Greenwich, in the Nautical Almanac. Now, a person observing one of these eclipses, and finding that he sees it 2 hours and 40 minutes earlier by *his* time, than it would be seen at Greenwich, becomes thus aware that his longitude is east of that of Greenwich by 40°; since the difference of time is 160 minutes, and every 4 minutes of time are equivalent to one degree of longitude.

491. These eclipses occur so frequently, that they afford the required means of readily ascertaining the longitude of any fixed station, where a telescope can be erected to observe them. But at sea they cannot be watched with sufficient accuracy; and it is necessary, therefore, to devise some other means of ascertaining the time at Greenwich. The simplest and most available of these means, consists in measuring the angular distance between the moon, and either the sun, or the more remarkable of the fixed stars; which distance, from the rapidity of the moon's revolution, is continually changing. Now, in the Nautical Almanac, a series of these distances is set down beforehand by calculation, for every three hours of Greenwich time; and thus an observer, measuring some of these distances with his sextant (§. 475), and looking for the corresponding distances in the columns of the Nautical Almanac (after making certain necessary allowances and corrections) finds out what would have been the time at Greenwich when his observation was made; and thus is enabled to compare that time with his own, precisely as if it were possible for him to see a rocket which it had been agreed to send up from Greenwich at that particular moment, or as if (to use an apt simile of Sir J. Herschel's) there were a clock-face and hands, keeping Greenwich time, set up in the heavens, so as to be everywhere visible.

492. Having ascertained the time at Greenwich, then, by any such observations, nothing more is necessary to the navigator, in order to determine his longitude, than to compare it with the time of the place where he then is. This he cannot find out by a transit instrument, since a transit instrument can only be used in a fixed observatory; but there are methods of ascertaining it, by measuring the elevation of the sun or of the stars,

before and after they have passed the meridian. If he have a watch, therefore, which will keep time well from one day to another, and is able to take observations for Greenwich time by the moon's distance, (which are termed *lunar* observations, or in common language *lunars,*) as often as he desires, correcting his watch each day by the sun or stars, as he changes his place on the earth, he can determine his longitude with sufficient accuracy for the purposes of navigation. But it will very often happen that for many days, sometimes even for weeks together, he is not able to obtain satisfactory lunar observations; and that he is deprived of this means of comparing his own time with that of Greenwich. It is under such circumstances, therefore, that the chronometer becomes of such essential service to him; for by its means he carries Greenwich time along with him, and can thus compare it, at any period, with the time of the spot on which he may be, as ascertained by observation of the sun or stars. If the chronometer can be relied on, therefore, the determination of the longitude is a very easy matter,—that is, when the time of the place can be ascertained; and it is seldom that an observation of the sun, or of some of the stars, cannot be taken at least once or twice in the twenty-four hours. But it must be remembered that, as even the best chronometers are liable to change their rates from some obscure causes, no reliance can justly be placed on a single time-keeper, as it may lead to considerable unsuspected errors. Even where two chronometers are compared, there is only greater certainty so long as they agree tolerably well; for if there be any considerable difference, it will be doubtful which chronometer is right. If three or more be compared, however, the faulty one will be almost certainly detected.

493. In the practice of navigation it is customary to rely chiefly upon chronometers for the determination of the longitude; but to *check* these, at intervals of a few days, by lunar observations; and this is especially necessary when the land is being approached, as any considerable error in the chronometers will then occasion great danger. Many ships traverse the Atlantic, however, without either chronometers or lunars; their owners

not being willing to incur the expense of chronometers, and their captains not being sufficiently instructed to make the necessary calculations from lunars. Their knowledge of their place depends, therefore, upon what is termed their *reckoning;*—that is, upon their estimate of the number of miles they have sailed (which is noted down every hour), and the course they have steered. This estimate is *checked* by the observations for latitude, if the course have been either directly north and south, or oblique. But if the ship have been sailing due east or west, the latitude remains the same, and there is no check upon the reckoning. It is often kept, however, by a practised navigator, with remarkable precision, when his course has been tolerably straight; but if he have been driven out of his course by storms, or drifted by currents, he is liable to form a very wrong estimate of his position.

494. The length of the degree of longitude varies with the latitude in which it is measured. This will become obvious on a little consideration. For at the equator, the degree will be 1-360th part of the *whole circumference* of the earth, and is therefore the same with the average of a degree of latitude, or about 69½ miles. The meridians approach nearer and nearer to each other, as they are traced from the equator to the pole, whilst the interval between them in degrees remains the same; hence the length of the degree decreases with the increase of latitude, since it is the 360th part of a smaller circle; and *at* the pole, all difference of longitude vanishes, since the meridians all meet there in a point. The decrease is more rapid near the poles, than it is near the equator.

495. It must be remembered, in regard to all the allusions which have been made to "Greenwich time," that this is selected as the standard of comparison, for the sake of convenience only. This is the site of the Royal Observatory; and the Nautical Almanac, which is published three or four years in advance, for the convenience of ships about to proceed on long voyages, contains tables of the celestial phenomena calculated for the time at which they will be seen there; by which the observer's distance east or west of Greenwich may be determined.

But other nations have similar tables calculated for their own observatories; and their longitude is estimated, therefore, by their own standard. The longitude of the observatory of Paris is 2° 20′ 24″ east of that of Greenwich.

Diurnal Rotation of the Earth.

496. So far as respects the *general* apparent movement of the sun, moon, and starry sphere, once round the earth in every 24 hours, it may be easily shown that it may be accounted for in two ways,—either by supposing that this movement really takes place, the earth remaining fixed in the centre of revolution,—or that the heavenly bodies are fixed, whilst the earth revolves in the contrary direction, round an axis which points to the Pole-Star. The former idea is that which naturally occurred to the ancient philosophers; who regarded the sun, moon, and stars as placed in the sky merely for the benefit of man; and who considered the earth as the most important body in the system, without dependence upon any others, but itself the immoveable centre round which they turned. The evidence of the senses appeared not only to sanction, but to require this explanation; and yet, as we shall presently see, it must now be unhesitatingly discarded. The second supposition appears to have been entertained by Pythagoras, who lived about five centuries before the Christian era; but it was not generally known to the world until the sixteenth century, when it was brought forwards by Copernicus, a Polish ecclesiastic, who ventured to disturb the rest in which mankind had slumbered for two thousand years, by proclaiming that it is not the starry sphere, but the earth—fixed and stable as it seems—which really revolves. The reasons by which he was led to this conclusion will gradually unfold themselves as we proceed; at present we shall inquire how it is capable of being reconciled with our own feelings.

497. Every one who has been in rapid motion, under such circumstances that he was not aware of it, well knows that, on looking at any near objects, *they* appear to be moving away from him, whilst he is at rest. The kind of motion which we experience in a carriage travelling along a smooth railway, is a

very good instance of this deception. After we have been for a short time accustomed to it, we are not conscious of it by anything in our own feelings; but if we look at the sides of the road along which we are travelling, we see them flying, as it were, rapidly backwards. We *know*, however, that *they* must be fixed; and therefore we *infer* that *we* are moving rapidly forwards. When the train in which we are is moving slowly forwards, and passes another train at rest, the illusion is more complete; for we may suppose the other train to be very probably moving in a direction contrary to our own; and thus we transfer (as it were) our own motion to it. Many other examples of the same fact are more familiar, though less perfect; such as the apparent motion of the banks of a river, produced by our sailing or rowing in the contrary direction; or the apparent rotation of the surrounding objects, when a person spins himself on the point of his foot. These examples are sufficient to prove, that the earth's rotation, although opposed, as it seems, to our own senses, is really quite consistent with their evidence. For it may be inquired of an objector to this doctrine, who maintains the fixity of the earth, *how* we should become aware of its rotation, supposing it to be thus put in motion. In other instances we become aware of our movement, either by the slight vibrations or shocks to which we are subjected, or by observing our change of position in reference to surrounding objects which we know to be fixed. Now we almost lose the first of these sources of information on a railroad, so even is the motion of a carriage over it; hence we trust entirely to the second, and we may be deceived by it, as just explained. The movement of the earth being perfectly uniform, free from all shocks and vibrations, and being shared in by all the bodies upon its surface, we gain no direct information respecting it from our feelings; and we have no objects with which to compare it, save the heavenly bodies. Hence it is absurd to object to it, on the ground that we are not conscious of the rotation; for, granting the rotation to occur, we should not become aware of it otherwise than as we do.

498. The arguments of Copernicus were not at once able to change the opinions which had prevailed for ages, strengthened

as these were by the supposed authority of Scripture; and it was not until the succeeding century, that his doctrine was generally received. It was powerfully supported by Galileo, who was able, by means of the telescope, to adduce many additional arguments in its defence (§. 554 and 617). For espousing this cause, however, he fell under the displeasure of the Inquisition, who had pronounced the doctrine of the earth's motion to be heretical; and he was led, by the dread of severe punishment, to promise not again to demonstrate that the earth moves. He seems, however, to have been unable to restrain himself from propagating what he believed to be truth; and having again been summoned before the Inquisition, and been wearied by long confinement, he signed, in his seventieth year, an abjuration of the doctrine, to the defence of which he had devoted the best part of his life. Yet it is recorded of him, that, on rising from his knees, after making this recantation, he whispered to a friend who was standing by him, "And yet it *does* move." During his confinement, he was visited by our own immortal Milton; who, doubtless, then learned from him many of those sublime truths, which he afterwards interwove, with such striking effect, in his Paradise Lost.

499. At the present day, no one having any pretensions to the name of a philosopher, doubts the rotation of the earth upon its axis; yet no proof of it can be given, that would be satisfactory to the uninstructed mind. There are four circumstances, however, which leave no room for hesitation, among those who can appreciate the value of the evidence they afford. The first of these is the fact, revealed to us by the telescope, of the similar rotation of the sun, and of all the planets on whose discs can be seen any marks, that may enable such a movement to be detected.—The second is the flattening of the earth at the poles, precisely to the degree which its centrifugal force would be calculated to produce, its rotation being performed at its present rate (§. 215).—The third is the result of the experiment of letting fall a stone from the top of a lofty tower; if the earth remained at rest, this would of course fall exactly at its base; but it does in reality fall a little to the eastwards of its base,

in consequence of its having partaken, at the moment of commencing its descent, of the motion of the top of the tower, which is moving through a larger circle, and consequently at a quicker rate, than the bottom (§. 167). This is the most direct and positive of all the proofs yet brought forward.—The last, however, is also of a very convincing nature. It is the prevalence, or rather the almost constant existence, of easterly winds in the equatorial region. The atmosphere does not rotate with the earth, except so far as it is carried round by its friction. In the temperate and polar regions, where the motion of the surface of the earth is comparatively slow, this friction is sufficient to carry the atmosphere along with it; but near the equator, the motion of the surface being much more rapid, the atmosphere is not carried along at the same rate; and the effect is therefore produced, of a wind constantly blowing in a direction contrary to that of the earth's movement (that is, from east to west); just as when a person travelling rapidly in a coach experiences a strong draught of air in the opposite direction, though the atmosphere may be perfectly calm at the time.

CHAPTER XV.

OF THE FIXED STARS.

500. Although the sun, moon, planets, and comets, whose motions seem to connect them with our own system, might seem to claim our attention in the first instance, yet we shall probably form more accurate notions respecting the part performed by that system in the universe, and of the vast extent of created being to which the laws that govern its operations are to be extended, if we previously inquire into our actual knowledge respecting the bodies composing the starry firmament.—Of the ideas entertained respecting them by the ancients, it is not requisite to say much. They do not appear to have formed any notion of their actual distance from the earth; and, considering our own globe as the centre of their motion, they accounted for their retaining the same positions with respect to each other, by supposing them to be fixed in a hollow sphere, by the revolution of which they all turned round together in a day and night. Their principal attention was given to the division of the stars into certain groups, which were conceived by them to have a likeness to the figures of men, animals, &c.; and various wild and romantic fables have been handed down to us in the writings of the Greek and Roman poets, with respect to the origin of these groups. Thus, some of the groups or constellations* were regarded by them as representing their gods; and others were considered as the figures of their chief heroes, who, after the conclusion of their mortal lives, were deified, and had places assigned to them amongst the stars. Of these fables, many appear to have originated among the

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* A name derived from the Latin words *con*, together, and *stella*, star; and therefore meaning a cluster or assemblage of stars.

Egyptians, from whom the Greeks, and after them the Romans, learned much of their astronomy; and some of the constellations thus named retain their appellations to the present day, although some have received other designations. Ptolemy, an Egyptian astronomer who flourished in the second century of the Christian era, enumerates forty-eight constellations; and these are still known for the most part under the same names. Many have since been added, however, in order to include stars which could not be well made to form a part of the original ones; and a large number of new ones had to be created, to distinguish those stars of the southern hemisphere, which were not known to the ancient astronomers, having been first noticed by the adventurous voyagers of the fifteenth century.

501. The accompanying figure, representing the constellation of Orion, is intended to give an idea of the mode in which the ancients combined, as it were, these starry clusters into figures. This constellation is one of the most beautiful in the heavens, on account of the number of large stars which it contains. Those that chiefly attract notice are the three large stars of the belt or girdle, which are arranged in an oblique line,—the two large stars at some distance above it, situated in the shoulders of the figure,—and the two other large stars, at about the same distance below, the one in the knee and the

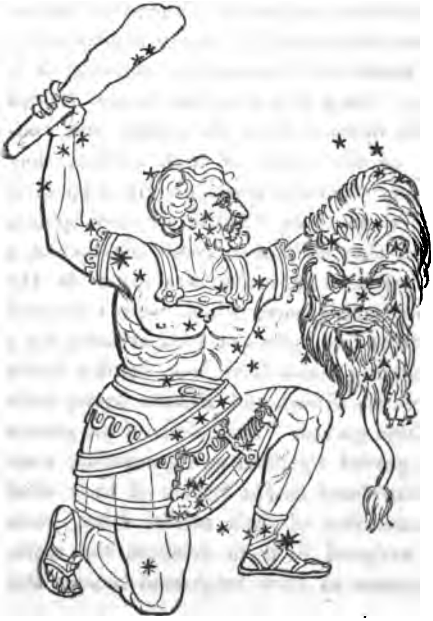
FIG. 149.

other in the foot. But there are many other stars of considerable size in this brilliant constellation;—those, for instance, which are contained in the lion's head, and in the sword or dagger below the girdle. A peculiar appearance about one of these will be noticed hereafter (§. 538).

502. The division into constellations, though quite arbitrary and fanciful, has this great advantage, that it enables us to *map out* the heavens, as we do the surface of the globe: and as, in *Geography* (or the description of the earth), we give names to the continents, islands, &c., which are distinguished by natural boundaries, and can thus indicate without any trouble the place where a particular occurrence took place, or where some particular scene is to be witnessed; so is it convenient, and, indeed, absolutely necessary in *Urano*graphy (or the description of the stars) to form similar divisions, for the purpose of fixing the place where any peculiar appearance is to be seen, or the star which is exhibiting certain movements. Thus, suppose a comet to become visible, and we wish to make its situation known to the public, we may say that it is to be seen near Orion's belt, or in the tail of the Great Bear; and, if we wish to be more precise, we may mention the particular star near which it is, each of the principal stars of each constellation being distinguished by one letter of the Greek alphabet. Were it not for a contrivance of this kind, no information could be given, without stating the measured place of the luminary in the skies; which would render it intelligible to those alone, who are provided with instruments to ascertain the spot meant. Hence we retain the names of most of the constellations that have come down to us from the ancients; whilst we forget the fables in which they originated. It is enough that astronomers understand one another; and there is nothing in any science so much to be avoided, as a confusion of names. The Great Bear is popularly known under the name of Charles's Wain, which was given to it in honour of the illustrious French monarch, Charlemagne; but its former or scientific appellation is alone mentioned on celestial globes or maps; and a person who consulted one of these in ignorance of the double name of

the constellation, would be much perplexed. It has also received the name of the Plough; which should be entirely disused.

503. It must not be supposed that, because certain stars appear to form groups, they are really near each other. The idea that the fixed stars are at anything like an uniform distance from us, has long been put aside, for reasons which will presently appear; and we have only to suppose that a certain set are seen by us in nearly the same line, to understand the *apparent* proximity of bodies that are really at an enormous distance. Let it be imagined that, from a commanding situation, we discern the peak of a distant hill;—that, some miles nearer to us, there is a church, whose spire is a little to the right of the hill; and that, some miles nearer still, there is a lofty and remarkable tree, which is seen by us a little to the left of the hill. Now, so long as we know that these objects are in reality one beyond another, we are not deceived by their apparent proximity; but if we imagine ourselves to be removed so far away, that we can form no estimate of the respective distances of these objects from us in a straight line, we shall easily perceive that their apparent closeness to each other will deceive us as to their real situations.—Let us make a comparison that shall render this truth, which lies at the foundation of all correct notions respecting the relative positions of the stars, still more obvious. There are few persons who have not observed the impossibility of forming any accurate idea of the distance of a luminous object on a dark night. The navigator might easily mistake the light of a star just above the horizon, for that of the friendly light-house, which is to guide him into his port, or to enable him to avoid the hidden danger; or he might, from error in his reckoning, mistake the beacon-light for a star.* The same mistake is not unfrequently made respecting the light from the window of a distant dwelling, which is seen just above the horizon, the darkness being too intense to enable the building itself to be discerned; for this could only be distinguished from that of a star, by reason of its greater steadiness, or by its

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* Such errors are prevented by giving to the light a distinct colour, such as red or green; or by causing it to disappear and return at intervals.

remaining fixed in the same position, instead of rising above the horizon, or sinking beneath it, as a star would do.

504. Or, again, if there were three lights on a wide open heath,—one of them proceeding from a large and brilliant lamp in a mansion at a distance,—another from a lamp of inferior brightness in a nearer dwelling,—and another from a farthing candle in the lantern of a passing traveller; we should be completely unable to form an estimate of their respective places and distances, if the intervening ground could not be seen by reason of the darkness. If the lights should happen to be nearly in the same line, they would appear to our eyes almost close together; and if their actual distances from us were in the proper proportion to their respective illuminating powers, their *apparent* sizes might be the same,—the farthing candle yielding as much light to us, by reason of its proximity, as either of the larger and brighter luminaries. We will further suppose that the traveller, whose lantern is at first our principal luminary, walks away from us, towards either of the more distant dwellings;—we shall not then see any motion in his light, since he is simply increasing his distance from us, and not turning to one side or to the other; —but it will gradually become fainter and fainter, and may at last, when actually removed to the same distance with the largest lamp, be lost sight of altogether. Hence we may conclude that the actual positions of the fixed stars with respect to each other, cannot be known from their apparent places as seen from the earth; and that the brightest of them are not necessarily the nearest.

505. There is much reason to believe, however, that, as a general rule, the distances of the fixed stars from us bear some relation with their apparent magnitudes, or rather with the different degrees of light which we receive from them;—that is, if we see two stars apparently near together, the one being large and the other small, we should believe their distances to be very different, the smallest being the furthest removed from us. They are all, however, so very remote, that the most powerful telescopes do not give the least information respecting their actual sizes; for the brightest,

> "Those sparks of light,
> The gems that shine in the blue ring of heaven,"

even when magnified most highly, look like most brilliant *points* of light, having no measurable diameter. Sir W. Herschel, when viewing the heavens with his 40 feet telescope,—the mirror of which, being 4 feet in diameter, took in an immense quantity of light, and reflected it to the eye,—was obliged to avoid the larger stars, on account of the glare of light which they produced; but he tells us that on one occasion, "the appearance of Sirius (the dog-star, the most brilliant of all the fixed stars) announced itself at a great distance, like the dawn of the morning, and came on by degrees, increasing in brightness; till this brilliant star at last entered the field of the telescope with all the splendour of the rising sun, and forced me to take my eye from the beautiful sight."

506. The total number of stars visible at once to the naked eye on a clear night, has been estimated at about 2000; but when the eye is aided by the telescope, the number is increased, just in proportion to the power of the telescope employed. No possible limit can be assigned to the number of stars, even supposing that those which are discernible with our present instruments could be reckoned; for every improvement in the construction of the telescope (and such improvements are continually being made) brings into view multitudes of stars which could not be previously distinguished; and as it would be absurd to attempt to set limits to such improvements, it would be in vain to endeavour to form an estimate, even of the number of stars with whose existence we may become acquainted, and much more of those which have their dwelling-place in those depths of space, into which man with all his ingenuity will never be able to penetrate.

507. Besides the stars which we distinctly recognise to be such, we notice on a clear dark night a broad luminous arch or band, known as the Milky Way, stretching across the whole sky from horizon to horizon. This band may be traced also through the southern hemisphere; and it thus forms a complete circle, surrounding our system at a vast distance. Although it is studded, as it were, with distinct stars, these evidently form no part of it, but merely have it for a back-ground, from being seen in the same direction. The general aspect of this band is

that of a delicate luminous cloud, presenting the faint and indistinct appearance which is termed *nebulous*,—a term which will have to be frequently employed hereafter.

> " A broad and ample road whose dust is gold
> And pavement stars, as stars to us appear
> Seen in the galaxy, that milky way
> Like to a circling zone, powdered with stars."

Now when the Milky Way is examined with telescopes of even moderate power, it is perceived that the nebulous appearance is due, not to any vapour-like assemblage of uncondensed matter, but to an innumerable multitude of very faint stars, apparently so near together that they cannot be distinguished by the naked eye.* Of the enormous number of stars thus crowded together, some conception may be formed from the fact mentioned by Sir W. Herschel, that he counted 70 at once, upon an average, in a space about one-fourth the apparent size of the moon's disk; from which he computed that 50,000 must have passed under his observation, during one hour, in a zone or band about a quarter of the whole breadth of the Milky Way. Other nebulous patches are to be seen in different parts of the heavens; and of these also, many are capable of being separated or *resolved*, by means of telescopes of greater or less power, into distinct stars; whilst many others cannot be so resolved, but retain their nebulous aspect even when examined with the assistance of the best telescopes. Of these *nebulæ* we shall have more to say hereafter.

508. For the sake of easy comparison, Astronomers have agreed to class the stars into different *magnitudes;* but it must be remembered that, by the term magnitude, *size* is not meant, but *lustre* or degree of light; for, as just stated, none of the fixed stars have any apparent diameter. The division is somewhat arbitrary; since there are no means of easily comparing the quantity of light given off by the different stars; but the following table exhibits the proportion assigned by Sir W.

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* Some of the ancient astronomers imagined that the Milky Way was an old and disused path of the sun! But Democritus had hit upon the real explanation of its appearance.

Herschel to the light of certain stars, which were selected as *types* or specimens of the six classes, that can be seen with the naked eye.

Light of a star of the average First magnitude . = 100
Second . . . . . = 25
Third . . . . . = 12?
Fourth . . . . . = 6
Fifth . . . . . = 2
Sixth . . . . . = 1

It should be borne in mind, that the apparent "magnitude" of any star must depend upon three conditions:—1st, the star's distance from us;—2nd, on the absolute size of its illuminated surface;—3rd, on the degree of brightness of that surface. Now as we have no means of judging of the two latter, we must not hastily conclude that the magnitudes of the stars are a measure of their relative distances; but that such an estimate is *generally* applicable appears from this important circumstance,—that the number of stars of each magnitude increases in proportion to the smallness of their light. Thus Astronomers restrict the *first* magnitude to about 15 or 20 stars; the *second* to 50 or 60 next inferior; the *third*, to about 200 yet smaller; and so on, the numbers increasing very rapidly as we descend in the scale of brightness, so that the whole number of stars already registered, down to the seventh magnitude, amount to from 15,000 to 20,000. Now these are not uniformly distributed over the sphere; for though the stars of the three or four highest magnitudes are scattered pretty equally in every direction, those of the smaller sizes are crowded together more and more as we approach the borders of the Milky Way; and the whole light of this is given by stars, whose average magnitude may be stated at about the tenth or eleventh.

509. Now this increase in the number of stars in proportion to the diminution of their brilliancy, corresponds so nearly with that which we should expect, if their diminution in brilliancy is occasioned by their increase of distance, that such may be confidently stated to be generally the case. For if we imagine an observer to be situated in the midst of a vast multitude of lamps or candles, arranged at tolerably uniform distances from each

other—say a foot in every direction;—he will see the small number in his immediate neighbourhood, distinguished beyond the rest by their brilliancy, and scattered widely apart on all sides of him;—a larger number will be seen within double the range, but these will appear less brilliant on account of their increased distance, and the same cause will make them appear closer together;—a still larger number will be seen at triple the range, still less brilliant, but nearer each other;—and the number of lights, and the diminution of their individual brilliancy, will continue to increase in like proportion with the distance, until at last we cannot distinguish the separate points, but they appear crowded or packed together in one continuous but faintly illuminated mass. It is fair to explain similar appearances in the heavenly bodies by similar causes, unless valid objections can be assigned; and thence to conclude, that the close packing and the diminished brilliancy of the stars of inferior magnitudes, result, in like manner, from their vastly-increased distance.

510. Now, if we imagine the luminous bodies to surround the observer equally in every direction, it is easy to understand that the continuous diffused luminosity of the most distant will form a sort of back-ground on *all* sides, against which the nearer and more brilliant lights will be seen. But let it be supposed that the cluster or group, instead of having the form of a globe (in or near whose centre the observer is supposed to be), is shaped like a cheese or millstone;—then the observer, placed in the centre, will be able to look out through its flat surfaces into empty space, and will see, on either side of him, the stars which form its *thickness*, studding the black ground presented by the darkness beyond;—whilst, if he look towards the circumference, his eye will meet with those more distant ranges of stars, whose near (apparent) neighbourhood to each other produces the indistinct luminousness already mentioned. Now, as these ranges will be only seen when the observer looks in some particular directions, they will appear to form an arch or band, stretching over his head from one point of the horizon to another.

511. It was by reasoning of this kind, that Sir W. Herschel came to the remarkable conclusion (which, though at first

thought ridiculous by many, is now adopted by all scientific astronomers) that all the stars distinctly visible to us really form part of one immense cluster, of which the boundary is formed by the Milky Way, whilst the position of our sun with its system is not far from its centre. The similitude of a cheese or millstone just adverted to might express tolerably well the form of our cluster; were it not that the Milky Way splits, as it were, at one part into two bands, which reunite again, so that we must imagine our cheese to be split at one part of its edge into two portions, which diverge somewhat from the general plane of the remainder. The accompanying delineation is probably a not very inaccurate view of our cluster or firmament, as seen from some of those more distant groups, of whose existence we have now positive evidence.

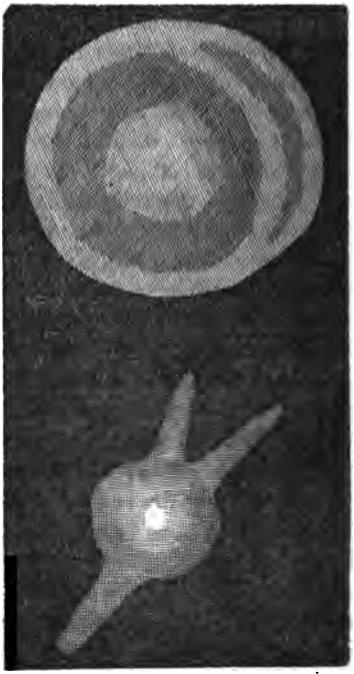

FIG. 150.—Ideal view of our cluster of stars, as seen from a distance; the upper figure represents its form as seen from the side; and the lower one, as seen from above or below.

512. In regard to the distance of even the nearest of the fixed stars, there have not existed until recently the least means of forming an accurate estimate. All that could be stated was, that their distance could not be less than *two hundred thousand* times the distance of the sun from the earth, or 19,200,000 *millions* of miles. The mode in which any such estimate must be made, is the same as that which is adopted for measuring the distance of the sun and planets from the earth, and is founded on what is termed the *parallax* of these bodies. This it will be

desirable to explain before going further. The term parallax is given to the *apparent motion* which objects exhibit, when the position of the observer is changed. Every one must have noticed that, when walking or riding through a country, there is a constant change in the aspect of the scene, arising from the different directions under which we view it; the apparent position of the nearer objects being continually altered, whilst that of the more distant remains the same. For instance, if we have a distant mountain in sight, we may travel for several miles before we can see any particular changes in its aspect; whilst various objects that at first intervened between ourselves and it have gradually been approached, have been left on one side, and are now at a considerable distance behind us. Thus, in the accompanying diagram, let A be the first position of the observer, and B and C two objects which he sees in the same straight line A B C D; if he change his position from A to E, he will

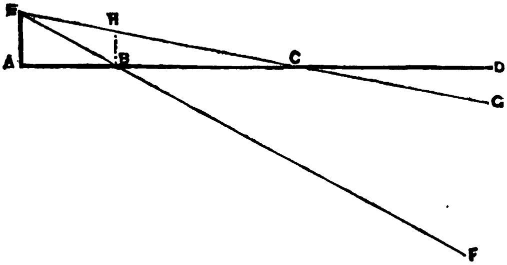

FIG. 151.

no longer see them in the same line, but there will be a distinct interval between them; for the rays from the object B will come to his eye in the direction B E, so that it is seen in the line E F; whilst those from the object C will come in the direction C E, so that the object is seen in the line E G. It will be observed, that the direction in which the object is seen is more altered in the case of the near object B, than of the more remote object C. The amount of this alteration in the apparent position of any object, is measured by the angle included between the lines joining the two stations with the object; thus, in the case of the object B, the *parallax* is the angle A B E between the lines A B and B E; whilst, for the object C, it is the angle A C E between the lines A C and C E. Hence, we observe that, the greater the distance of the object, the smaller will this angle be, whilst the line A E (which represents the amount of real change in the observer's place) remains the same. Now, by a very simple calculation, the mathematician who knows the amount of the angle A B E or A C E, and the length of A E, can ascertain the distances A B and A C of the bodies B and C from A; and it is from calculations of this kind, that the distances of the sun, moon, and planets, have been determined.

513. Now, if the fixed stars were moderately near to us, we should see their relative positions changing, during each of their (apparent) daily revolutions round the earth; since they are seen in a different direction, when near the horizon, from that in which we view them when they have risen to the zenith. Such a difference is perceptible in the case of the moon, whose apparent position is changed with respect to the sun and stars (after making the proper allowance for her real motion) as she makes the circuit through the heavens; and from the amount of this change, which is termed the moon's parallax, her distance from the earth may be estimated. Again, supposing the point C (Fig. 151), to represent the place of the sun, and B to represent that of Mercury or Venus; this planet, to an observer situated on the earth at A, will appear to be crossing the sun's disc; but to an observer at another part of the earth at E, the planet will not appear in a line with the sun, and it must, in fact, move onwards to H, before it is seen upon his disc. Hence, if we know the interval between the two observers, and the length of time which elapses between the times when the planet appears to the one and to the other to be in a line with the sun, we can determine the angle A C E with greater exactness than we could by any ordinary measurement; and we thus obtain from the *transits* (§. 561) of Mercury and Venus the best opportunities for ascertaining the sun's parallax, and consequently our distance from him. Not the slightest alteration, however, can be perceived in the relative places of the *stars* during their daily passage through the sky.

514. But if the stars, though not near enough to be affected by the daily change in their position in regard to the earth, were still at a distance not exceeding by many times that of the sun, a very sensible alteration would be observable, when the earth alters its position (as it will be shown in the next chapter to do every six months), to the amount of 190 millions of miles. Yet so vastly is this exceeded by the distance of the nearest of them, that it has been until recently a matter of uncertainty whether they exhibit the least change of position, or, in other words, exhibit any parallax; although the perfection of astronomical instruments is now such, that an angle, such as A C E, Fig. 151, could be measured with certainty, even if it were no more than a single *second*, or 1-3600th part of a degree. The sides of the triangle, therefore, are of such inconceivable length, that, although the base A E measures 190 millions of miles, the angle at its vertex can scarcely be appreciated. Numerous attempts have been made to determine whether any of the stars have such an *annual parallax*,—that is, a change of apparent position resulting from the earth's annual movements; but, until recently, these have all been unsuccessful. "After exhausting every refinement of observation," wrote Sir J. Herschel in 1834, "astronomers have been unable to come to any positive and coincident conclusion upon this head; and it seems, therefore demonstrated, that the amount of such parallax, even for the nearest fixed star which has hitherto been examined with the requisite attention, remains still mixed up with, and concealed among, the errors incidental to all astronomical determinations." Now if the parallax were as much as a single second, the distance of the star exhibiting it could not be less than 200,000 times the distance of the earth from the sun, or 19,200,000 millions of miles.

515. In such numbers the imagination is lost; and the only mode of conceiving of such intervals at all, is by estimating the time which it would require for light to traverse them. Now we know from other sources (§. 622) that light travels at the rate of about 192,000 miles per second; consequently it would require 100 million seconds, or about three years, to per-

form the journey,—or, in other words, we should not see a star newly placed at that distance, for three years after it had begun to shine, and we shall see it for three years after it shall have ceased to exist. In the year 1838, however, Professor Bessel of Königsberg announced, as the result of a most careful and laborious series of observations on a star in the constellation Cygnus, that it has a parallax amounting to about *one-third of a second;* and that, upon this, its distance from the earth may be calculated with tolerable accuracy. He has since (1840) slightly corrected his first series of observations, and has given ·0″·3483, or something more than a third of a second, as the annual parallax of this star; which makes its distance about 592,200 times the distance of the earth from the sun,—a distance which light would require 9¼ years to pass through. This has been truly spoken of as "a magnificent conquest;" for it is so, both in regard to the sublimity of the object to be attained, and the amount of intellectual labour bestowed upon it. If we estimate the comparative distances of the other stars by the proportion of light we receive from them, we shall be led to the astounding conclusion, that many, even of those in the Milky Way, must be so distant, that their light would be at least *a thousand years* in travelling to our earth; though its rapidity of movement is such, that it comes to us from the moon—vast and almost inconceivable as *her* distance (237,000 miles) is, in comparison with any of which we can form a definite idea—in little more than *one second* of time.

516. Of the actual magnitudes of the Fixed Stars, their light and distance, compared with those of the sun, afford us our sole means of forming an estimate. It has been ascertained by very careful measurements, that the light of *Sirius*—the most brilliant of all of them—is to that of the sun, as 1 to about 20,000 millions. The sun, therefore, in order that it should appear to us no brighter than Sirius, would require to be removed to 141,400 times its actual distance.* It has been shown (§. 514) however, that the distance of Sirius cannot be so little as that of

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* The proportional intensity of light being inversely as the squares of the respective distances (§. 91).

200,000 times that of the sun, and is probably a great deal more. Supposing that the sun were removed to 282,800 times its actual distance, its light would be only one-fourth of that of Sirius; so that, if this be the real distance of that star (and it is probably much less than the reality) its light must be equal to that of four suns. "Now, for what purpose," it is well inquired by Sir J. Herschel, "are we to suppose such magnificent bodies scattered through the abyss of space? Surely not to illuminate *our* nights, which an additional moon of the thousandth part of the size of our own would do much better,—nor to sparkle as a pageant void of meaning and reality, and bewilder us among vain conjectures. Useful, it is true, they are to man, as points of exact and permanent reference; but he must have studied astronomy to little purpose, who can suppose man to be the only object of his Creator's care, or who does not see in the vast and wonderful apparatus around us, provision for other races of animated beings. The planets derive their light from the sun; but that cannot be the case with the stars. These doubtless, then, are themselves suns; and may, perhaps, each in its sphere, be the presiding centre round which other planets, or bodies of which we can form no conception from any analogy offered by our own system, may be circulating."

"And these are suns!—vast, central, living fires,
Lords of dependent systems, kings of worlds
That wait as satellites upon their power,
And flourish in their smile. Awake, my soul,
And meditate the wonder! Countless suns
Blaze round thee, leading forth their countless worlds!
Worlds—in whose bosoms living things rejoice,
And drink the bliss of being from the fount
Of all-pervading love. What mind can know,
What tongue can utter all their multitudes!
Thus numberless in numberless abodes!
Known but to Thee, blest Father! Thine they are,
Thy children, and thy care—and none o'erlooked
Of Thee! No, not the humblest soul that dwells
Upon the humblest globe, which wheels its course
Amid the giant glories of the sky,
Like the mean mote that dances in the beam
Amongst the thousand mirror'd lamps, which fling

> Their wasteful splendor from the palace wall.
> None, none escape the kindness of Thy care;
> All compassed underneath Thy spacious wing,
> Each fed and guided by Thy powerful hand."[*]

517. Although we are accustomed to speak of the fixed stars as undergoing no visible change whatever, yet they present to us several most interesting and remarkable phenomena. Thus, there are several which are not distinguished from the rest by any obvious peculiarities of appearance, but which undergo a periodical increase and diminution of lustre, involving in one or two cases a complete extinction and revival. These are called *periodical* stars. One of the most remarkable, in regard to the shortness of its period, is the star called Algol, in the constellation Perseus. It is usually visible as a star of the second magnitude, and retains this size for 2 days and 14 hours. It then suddenly begins to diminish in splendour, and in about 3½ hours it is reduced to the size of a star of the fourth magnitude. It then begins to increase, and in 3½ hours more regains its usual brightness,—thus going through all its changes in about 2 days 21 hours. The cause of this variation was supposed by its discoverer (M. Goodricke) to be the revolution round the star of some opaque body, which, when it interposes between its disk and ourselves, cuts off a portion of its light. The effect strikingly resembles that which is produced by the same cause in the revolving lights of light-houses. It is interesting to remark that this variation, first discovered in 1782, was noticed not only by a professed astronomer, but also by an unlettered peasant of the name of Palitzch, residing near Dresden; who, from his familiar acquaintance with the heavens, had been led to distinguish this star from so many others, and had ascertained its period. It was by the same individual that the anxiously-expected comet, whose return in 1759 had been predicted by Dr. Halley, was first seen; he detected it nearly a month before it was observed by any of the astronomers, who were watching for it, armed with their telescopes.

518. The most remarkable of the periodical stars, in regard

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[*] From an Address to the Ursa Major, by the Rev. H. Ware of Boston, New England.

to its complete extinction at intervals, is the one named Omicron, in the constellation Cetus; its variation was first noticed by Fabricius, in the year 1596. It appears about 12 times in 11 years, its period being about 334 days; it remains at its greatest brightness about a fortnight, being then on some occasions equal to a large star of the second magnitude; it decreases during about three months, till it becomes completely invisible, in which state it remains about five months; it then again becomes visible, and continues increasing during the remaining three months of its period. It is a peculiarity of this, and of one or two more of the periodical stars, that the variations are not regular. It is stated, that for four years this star did not appear at all; and another small periodical star in the constellation Cygnus, the period of whose variation is about 13 months, was scarcely visible, during three years, at the times when it ought to have been most conspicuous.

519. These variations prepare us for other phenomena, to which at present no character of regularity can be attached; though it cannot be doubted that they too are subject to laws which we might discover, if our opportunities for observation were sufficient. There have been seen, at different times, *new* stars,—or rather stars which were not previously visible; but these have had only a temporary lustre, blazing for a while with extraordinary lustre, then dying (as it were) and leaving no trace behind. The earliest star of this kind on record, is that which suddenly appeared in the year 125 B.C., and is said to have been the occasion of the catalogue of stars which was then drawn up by Hipparchus. Another blazed forth in A.D. 389, remained for three weeks as bright as Venus, and then disappeared altogether. There are records of similar appearances in the years 945, 1264, and 1572; and the near coincidence of the *intervals* between the first and second, and the second and third of these, together with the coincidence in the *place* of their appearance—so far as can be ascertained from the imperfect observation of the first two—leads to the suspicion that they result from a periodic change in the same star, having an interval of something more than 300 years. If this be the case,

we may expect a re-appearance in the latter part of this century. The appearance of the star of 1572 was so sudden, that Tycho Brahe, a celebrated Danish astronomer (§. 555), returning one evening from his observatory to his dwelling-house, was surprised to find a group of country-people gazing at a star, which he was sure did not exist half an hour before. This was the star in question. It was then as brilliant as Sirius, and continued to increase, till it surpassed Jupiter when brightest, and was even visible at mid-day. It began to diminish in December of the same year; and in March, 1574, it had entirely disappeared. A star of this kind, not less brilliant, burst forth in the constellation of Serpentarius in October, 1604; and remained visible for a year, after which it completely vanished.

520. Similar phenomena, though of a less splendid character, have been since noticed; and they offer an abundant field for observation and speculative inquiry. Are these all to be accounted for, like the variations of the periodical stars, by the revolution of an opaque body, sometimes eclipsing their light; or are these changes due to alterations in the constitution of the star itself? There is this objection to the idea of their similarity to the periodical stars;—that in the former, there is a continued lustre, occasionally diminished or interrupted; whilst in the latter it is the absence which is continued, and the lustre which is occasional. Now the occasional interposition of an opaque body, such as would take place during its revolution round the star, fully accounts for the former; but it would require the supposition that the opaque body has the form of a ring, having a gap or opening on one side, to account in the same manner for the rare appearance of the stars of the latter class. It is probable, then, that we are to regard changes in the constitution of the individual stars, as the cause of their occasional appearance and subsequent disappearance. This idea corresponds with the fact, that many stars, whose places have been accurately noted in catalogues, have altogether disappeared from the heavens. Some of these supposed losses may not be real, having originated in mistaken entries; but in regard to several, there is no doubt. They may, however, be analogous to the stars previously

described; and may burst forth again into splendour, after a long period of darkness.

521. An explanation of these appearances has been offered by Prof. Nichol, which does not seem improbable. The amount of light given off by our sun is continually varying, in a slight degree, in consequence of the occupation of a minute portion of his surface by spots of greater or less magnitude (§. 591); and there is some reason to believe, that one side of his globe is rather less brilliant than the other; so that, as he turns on his axis in about 25 days, there is a constant, though trifling, variation in the amount of light and heat which we receive from him. Now, if we suppose that this variation is more considerable in the case of the *periodical* stars, so that a greater or less part of one side is not luminous at all, we shall have a satisfactory explanation of their regular diminution of lustre, or (in some cases) entire but temporary extinction. And if we further suppose that in the *occasional* stars, the principal part of the surface is dark, whilst the illuminated space occupies but a small portion of it, we shall account for their long period of darkness, and for their occasional brilliancy; provided that it be admitted (which from analogy, as well as from other considerations to be adverted to in the last chapter, seems highly probable) that the stars, like the sun, rotate on their own axis.

522. How wonderful the thought, that for years, and perhaps for ages, after these changes have taken place, we remain ignorant of them,—that most probably even now have the rays of the brilliant star of 1572 been shot forth towards our planet, though these will not reach us for nearly half a century to come, —and that its disappearance from the astonished gaze of Tycho was in consequence of a withdrawal of its light before that illustrious astronomer himself came into existence.

"Yea, glorious lamps of God! He may have quenched
Your ancient flames, and bid eternal night
Rest on your spheres; and yet no tidings reach
This distant planet. Messengers still come
Laden with your far fire, and we may seem
To see your lights still burning; while their blaze
But hides the black wreck of extinguished realms,
Where anarchy and darkness long have reigned."
(Rev. H. Ware.)

523. We now come, however, to a class of phenomena which appear more wondrous still, because more unexpected—from its dissimilarity from anything that ordinarily comes beneath our notice;—and which is yet a peculiar source of interest to the philosopher, as affording him the means of demonstrating, that the great law of mutual attraction is not confined to our own system, but extends its agency through the illimitable realms of space. It has been observed, at least since the time of Galileo, that, whilst the greater part of the nearer stars appear scattered through the heavens with a tolerably equal distribution, so as to be at medium or average distances from each other, there is a large class which appear to be in closer neighbourhood than the hypothesis of equal scattering will account for. It has been already pointed out (§. 503) that if two stars be nearly in the same line from the earth, they will seem to an observer very near together; and it is in this manner that we are to account for most or all the instances, in which two stars having this close proximity can be distinguished by the naked eye. But the case we are now to consider, is the not unfrequent one of two or more stars, which are so close that they appear as a single star to the naked eye, and cannot be separated without the assistance of telescopes. Until the time of Sir W. Herschel, it had been supposed, that the conjunction of these also is *optical* and not *real*, being dependent upon their situation in the same visual line, though one might be supposed to be at many times the distance of the other. But his attention having been particularly directed to these *double stars*, in the hope of ascertaining the annual parallax through their means, he soon found out that their number was much greater than could be accounted for, with a fair degree of probability, in this manner. It is only in the Milky Way,—where the stars appear too crowded (in consequence of their number and remoteness) for the unaided eye to distinguish the intervals between them,—that we should expect to meet frequently with such coincidences. When the vast extent of the remainder of the sky is considered, and compared with the moderate number of stars scattered over it, we at once perceive it to be greatly against probability, that

any large proportion of them should be immediately, or even nearly, behind one another.

524. The argument is thus familiarly illustrated by Prof. Nichol :—" Suppose a number of peas were thrown at random on a chess-board, what would you expect ? Certainly that they should be found occupying irregular or random positions; and if, contrary to this, they were, in far more than average numbers, arranged by *twos* on each square, it would be a most natural inference that here there was *no* RANDOM *scattering;* for the excessive prevalence of the binary arrangement would indicate forethought, design, *system*." Hence it is evident that the larger the number of stars of a certain magnitude, the more likelihood there is of the conjunction being merely optical; whilst among the comparatively few stars of the highest magnitudes, the coincidence would almost certainly indicate a real connection between the two bodies. Further, it will be evident that, the nearer the proximity, the less is the probability of the coincidence being accidental; or, in other words, we are more entitled to suppose that the neighbourhood of any two stars is apparent and not real, when they are far enough from each other to be distinguished with little difficulty, than when they are so close that the assistance of the best telescopes is required to separate them. For in such a case as that of the random scattering of the peas on the chess-board, there is much greater probability that we should find a dozen pairs within a quarter of an inch from each other, than that we should find them in absolute contact.

525. Now it has been ascertained that there are 653 double stars of considerable magnitude, the intervals between whose two bodies do not exceed 32 seconds, or the apparent breadth of the planet Jupiter; and it has been calculated that the number of these which might be expected to coincide optically, is no more than 48. Hence there are 605 whose neighbourhood remains to be accounted for. Of 612 stars of a smaller magnitude, but having the same range of apparent distance, it has been calculated that 129 may probably be only visually connected; and that the remainder must have some other relation. But when

the interval is increased from 30 seconds, or the apparent diameter of Jupiter, to 900 seconds, which is about half the breadth of the sun, the probability of the *optical* connexion becomes much greater; so that out of 25 that have been observed at the latter distance, 21 or 22 are likely to have only this accidental relation. The difference between the two may be simply stated in this manner. The stars that are only visually related, through being in the same line from the earth, would be found to undergo a complete change in their mutual positions, if they were viewed from a different point (§. 512); but the stars that really are close and connected, will appear so under all aspects.

526. Particular attention was given to these double stars by Sir W. Herschel, from the belief he entertained that careful observation of their positions in regard to each other would enable the annual parallax to be ascertained with more certainty than it could be in any ordinary mode;* and he applied himself to determine the precise directions in which they lay with regard to each other. Thus, supposing one of the bodies to be exactly upon the meridian or southern line, the other might be above or below it, to the east or to the west. He had scarcely entered, however, upon the series of observations requisite to determine with the requisite precision the *angles of position* and mutual distances of these stars, before his attention was arrested by a most novel and unexpected change. Instead of finding, as he anticipated was possible, a small alternate increase and decrease in their distances and angles of position, taking place in each year as the result of the earth's change of position, he observed in numerous cases a *regular progressive change*, which could only be accounted for, by supposing that the stars are actually in motion round some fixed point. The appearances which such motions will exhibit to us, manifestly depend upon the direction in which we view them. Thus a person at a distance moves one ball round another in an *upright* circle, so that we look fully upon its whole path; we then see the revolving body

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* The result has completely justified this opinion; for it has been by the careful observation of the double star 61 Cygni, that Prof. Bessel has now clearly proved the existence of annual parallax (§. 515).

constantly maintaining its distance from the central one, but continually changing its angle of position; since a line joining the two would point in a different direction, with every change in the place of the revolving body. But supposing that the body be moved in a *horizontal* circle, the plane of which is in the direction of our line of sight, so that we see its *edge* and not its *face*;—the revolving body will be seen to move from one side of the centre to the other, apparently in a straight line, sometimes passing in front of the central body and sometimes behind it; and their apparent distances would be thus continually altered, without any variation in their angular position, since a line joining the two would always point in the same direction.

526*. Among the numerous double stars, are some whose paths are seen in the first of these directions, and others in the second; whilst there are many more whose orbits are presented to us obliquely, so that in their revolution they change both their distances and their angles of position. One of the first stars in which this peculiar revolution was observed by Sir W. Herschel is the one designated as ξ in the Great Bear; and the progressive changes it has since exhibited are represented in the accompanying diagram, from which it is evident that we can see the revolution almost in the first-named position; the distances

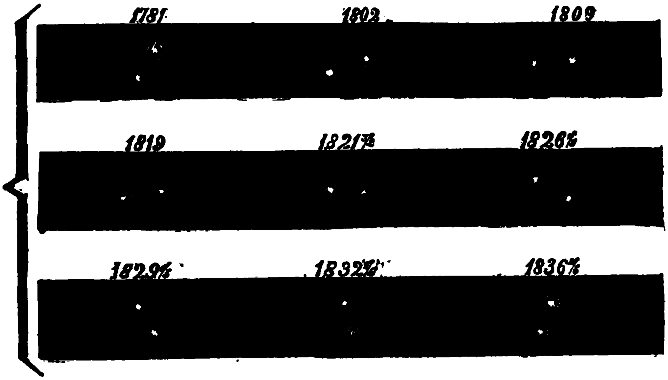

FIG. 152.

varying but very little, whilst the angle of direction is continually changing. We observe that, after undergoing a nearly complete revolution, the two stars have come, in 1836, nearly into the same position which they had in 1781, when it was first registered by Sir W. Herschel; and by 1839 they would have returned into precisely the same relative positions, the period of their revolution being 58¼ years. This is nearly the shortest periodical revolution that has yet been observed among the stars thus connected, which are termed *binary* stars, to distinguish them from those which are merely visually *double*. The star η Coronæ, however, has a period of only 43⅓ years; and has far advanced in its second revolution, since its motion was first discovered by Sir W. Herschel. In general, however, the period is much longer; in γ Virginis it has been estimated at nearly 629 years; whilst in γ Leonis, it is not less than 1200.

527. Of all the binary stars yet observed, the former of these two is probably the most interesting, not only on account of the great length of its period, but also on account of the great variation in the apparent distance, and in the rapidity of motion, of the individuals composing it. They are of nearly equal lustre, and together appear like a star of the 4th magnitude. At the beginning of the last century, they were much wider apart than they are at present; and were, in fact, entered in the catalogues of the time as two distinct stars, being then separable with telescopes of very moderate power. Since that time they have been continually approaching, and are now so close that only a first-rate telescope will enable them to be separately distinguished; their appearance in any others being that of a single elongated star. Hence the plane in which they move must be seen by us nearly edgewise. It fortunately happens that Bradley, who was Astronomer Royal in 1718, noticed and recorded in the margin of one of his observation-books, the apparent direction of their line of junction, as being parallel to that of two remarkable stars of the same constellation; and this remark, casual and unimportant as it seemed, has been the means, together with the observations which have been made since the commencement of the present century, of enabling Sir J.

Herschel to determine the orbit with nearly as much precision as if we looked fully upon it.

528. In this manner it has been shown that the individuals composing a binary star have a motion round each other, or rather round their common centre of gravity (§. 120); and that they move in elliptic orbits, according to laws precisely the same as those which will be shown to govern the motions of our own planetary system,—a system which, in comparison with the vast universe thus opened to us, is immeasurably smaller than the minutest atom discerned by the microscope, when compared with the bulk of the globe we inhabit. If we estimate the distance of the individuals of the binary stars from each other, as not less than that of the sun from the nearest of the fixed stars (which we seem perfectly justified in doing), the rapid movement of the comet of 1680, which in one part of its revolution swept along at the rate of nearly a million of miles in an hour, must be as nothing to theirs.

529. The number of *double* stars, whose existence was noted, and whose positions were measured by Sir W. Herschel, amounted to upwards of 500; and this number has been since augmented to 2640, by the labours of his successors in this field of observation. A still further increase may be anticipated, from the observations of Sir J. Herschel at the Cape of Good Hope, which have not yet been made public. Of these, however, it *may* prove that only a small proportion are really *binary* stars,—that is, have a mutual revolution round each other. Professor Struve, of Dorpat, in a catalogue published a few years since, states that there are 58 in which such a change is certain, 39 in which it is probable, and 66 in which it is suspected; and he considers that we may assume, on tolerably good grounds, that, altogether, 101 double stars are entitled to be considered as *binary* combinations. It must not be imagined, however, that, because no motions have been detected in the others, they do not take place. For it must be remembered, how minute are the distances that have to be measured; and how many observations at distant intervals must be needed, to establish the fact of

the revolution in the case of those whose periods are long. It is now not much more than 55 years since measurements of this kind were first made; and scarcely 40 years since the probability of orbitual motion was first announced. Many of these stars may have a period so long, that this brief space is not sufficient to enable the least change to be detected in them, with our imperfect means of observation; and a century or more may elapse, before their motion shall have been ascertained beyond a doubt.

530. The differences of colour which manifest themselves among the Fixed Stars, are often displayed with remarkable vividness by the stars of these binary systems. The haziness of our atmosphere prevents these differences from being so evident in our climate, as they are in those countries where their light comes to the observer more brilliantly and uninterruptedly; but still a variety of hue is very distinguishable among the stars of the first magnitude, and can be discerned with a telescope in those of inferior brightness. These hues seem to change in the course of long periods of time. Thus, Sirius (the Dog-star) was celebrated by the ancients as a red star, but it is now brilliantly white. The contrast is remarkably seen in many of the binary stars; for wherever one of the pair possesses any peculiar hue, the other presents what is optically termed the *complementary* colour,—that is, the colour which, united with the other, will form white or colourless light.* Thus, if one of the stars be red, the other will have a green hue, resulting from the mixture of blue and yellow; or if one be green, the other will be red. On the other hand, if one of the stars be yellow, the other will be purple, from the mixture of red and yellow, and *vicè versâ.* Lastly, if one of the stars be blue, the other will be orange, from the mixture of red and yellow; and *vicè versâ.*

531. It has been suggested, that this phenomenon is the mere effect of contrast; proceeding from the same cause, as the dark spot which is seen on a piece of white paper, when the eyes are turned upon it after looking at the sun or some very lumi-

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* See Treatise on OPTICS.

nous body,—or as the red spot on white paper, when we have been looking at a bright-green object. If this were true, the colour should be only exhibited by one of the stars, and the other should only show its peculiar tint when viewed at the same time with the first. But there are several double stars, in which this is certainly not the case, their distance being sufficiently great to enable us to look at them *separately* through the telescope; and it is then seen that each has its own proper colour, with which it impresses the eye as well when the other is absent as when it is present. "It may be more easily suggested in words," remarks Sir J. Herschel, "than conceived in imagination, what variety of illumination *two suns*—a red and a green, or a yellow and a blue one—must afford to a planet circulating about either; and what charming contrasts and grateful vicissitudes,—a red and a green day, for instance, alternating with a white one and with darkness,—might arise from the presence or absence of one or other, or both, above the horizon. Insulated stars of a red colour, almost as deep as that of blood, occur in many parts of the heavens; but no green or blue star (of any decided hue) has, we believe, ever been noticed, unassociated with a companion brighter than itself."

532. Combinations of *two* stars are not the only ones, however, in which this kind of union has now been ascertained. Guided by the clew which the researches of Sir W. Herschel afforded him, Prof. Struve has examined numerous sets of triple stars,—that is, of conjunctions of *three* bodies; and he has ascertained that the number of these is many times greater than could be accounted for, on the simple probability of their having the same visual direction. In several of them, such changes have already been recognised, as to lead to the belief—almost to the certainty—that they also have a motion round their common centre of gravity, and are subjected to the same laws with binary compounds. Even more complex systems have been discovered. Groups of four and even of five have been observed to present such appearances, as sanction the belief in their mutual relation; and the same view has been

extended with much probability to the interesting group of the Plèiades, which consists of 44 stars of the seventh and higher magnitudes, contained within a circular space of two degrees in diameter; for the probability of their merely optical coincidence can be proved to be so excessively small, as almost to approach an impossibility.

533. From combinations like these, we are naturally led to consider whether various stars of our firmament, distant from one another though they are, have any mutual connection and related motions. If our cluster could be regarded from that distance, at which it would présent the aspect shown in Fig. 150, the probability of such a connection would appear much stronger than it does to us, who are placed in its interior, and know only the vast distances which separate its nearest members. Yet, by the law of mutual attraction, there would be a tendency of all the individual stars towards each other, and towards the centre of the whole mass; and such tendency could not be counteracted, except by giving to them all a movement around their common centre of gravity, like that which prevents the planets from being drawn towards the sun. Now, it is quite certain that many of the so-called Fixed Stars have sensibly changed their places in the heavens, since these were first recorded; and that our sun partakes of this general movement, —sweeping rapidly along, with his train of planets, towards a point in the constellation Hercules.* Many thousands of years must elapse, however, before the change of position can produce any sensible effects upon the appearance of the heavens from our globe, or upon its own condition,—so vast are the distances to be traversed; and it will only be by the combined observations of the many astronomers, who are now labouring with patience and disinterestedness for those who come after them, that such changes can be accurately known, and their laws determined.

534. We now quit our own cluster or firmament,—in which are to be included (as already explained) all the stars that we

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* This motion, first announced by Sir W. Herschel, has been since denied; but its existence has recently been completely established.

can distinguish with the naked eye or with telescopes of moderate power, and which seems bounded by the Milky Way as by a band or zone,—and pass on to consider the evidence we have of the existence of other similar clusters, far beyond the limits of our own. There may be seen, in different parts of the heavens, even with the naked eye, luminous spots resembling stars surrounded by a bright halo, or comets without tails; and many of them *have* been mistaken for comets, until their fixed positions proved the mistake. These, when viewed with telescopes of moderate power, continue to present the same appearance; but when examined with more perfect instruments, they are seen to be composed of *clusters of distinct stars*, having more or less of the globular form. From the small amount of light which every individual star transmits, it is evident that the cluster must be far beyond the confines of our own group; since they are far inferior in brightness to the smallest stars of the Milky Way. But from the number which are crowded together in an area whose apparent size is very small, the light transmitted by the whole cluster is often sufficient to give it a considerable degree of brilliancy. This is especially the case towards the centre, where, of course, we shall see through the thickest part of the cluster (supposing it to be of a globular

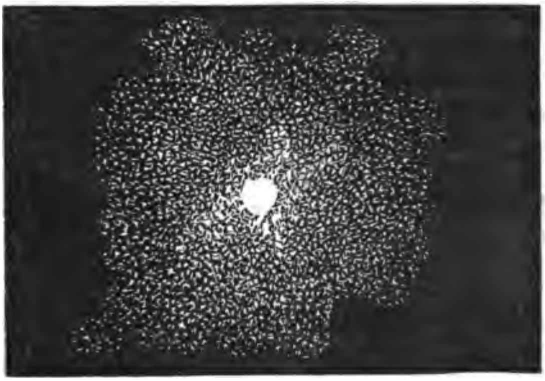

FIG. 153.

form), and where there will consequently be the most intense brightness. The appearance of one of the most beautiful of these clusters,* which are termed *nebulæ*, from the cloudy appearance they present until separated by very high magnifying powers into their component stars, is shown in the accompanying figure; which gives, however, but a very faint idea of its beauty. But it may generally be observed, as in this instance, that the brightness of the centre is greater than would result from the simply optical cause just mentioned; so that there must be a real crowding together of the stars towards the centre of the group. To attempt to count the stars composing such clusters, would be quite out of the question; but it is certain that many of them must contain ten or twenty thousand stars, compacted or wedged together into a round space, whose apparent size is not more than a tenth part of that covered by the moon.

535. There are numbers of other *nebulæ*, however, which require still more perfect telescopes for their separation into distinct stars; and which, therefore, may be regarded as at a vastly greater distance. These, of course, do not present the same degree of brilliancy to the eye; though many of them, by reason of their enormous size, are still distinguishable by it. Of this kind are the Magellanic Clouds of the southern hemisphere, which are so named after the celebrated voyager who first noticed them. They are two patches, which have the diffused luminousness of the Milky Way, but are very much fainter. They have recently been examined by Sir J. Herschel at the Cape of Good Hope; and he describes the larger of them as consisting of globular clusters and nebulæ of various sizes and degrees of condensation (or crowding); the space between them being filled up with a diffused luminosity forming a bright ground on which the other objects are scattered. In this he could not distinguish separate stars, even with his highest powers; but he believes it to be made up, like the rest, of distinct individuals, far more distant and therefore more indistinct. This bright ground, when

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* This is the celebrated nebula in the constellation Hercules. It is visible to the naked eye; and in an ordinary night-glass it appears like a small round comet.

viewed with such a telescope, closely resembles the Milky Way, as seen by the naked eye; and it can scarcely be doubted, that, with still higher magnifying powers, it would be seen to consist of distinct stars. At present, therefore, it is in the condition termed by the astronomer *irresolvable*, since he cannot *resolve* or separate it into the parts of which it probably consists: but there is reason to believe that it *may* be resolved with still more perfect instruments. We shall find the contrary to be the case in regard to some other nebulous patches presently to be described (§. 538). One of the most remarkable circumstances in the constitution of these Magellanic Clouds, is the crowding together of many distinct clusters, and the curious form which one of them presents. This consists of a number of loops united in a kind of unclear centre or knot, like a bunch of ribbons disposed in what is called a "true lover's knot!"

536. The resolvable Nebulæ are scattered in great numbers through the heavens; and, from the different degrees of magnifying power which are required to make out their individual stars, there is good reason to believe that they are at varying distances from our own cluster. To an observer living in one of the bodies of which either of these clusters is composed, the appearance of the heavens will be determined by the arrangement of the stars in his own group. If it have the globular character, seen in Fig. 153, and he be situated near the centre of it, the number of stars in his near neighbourhood, and therefore of the first magnitude, will be very considerable; and these, as well as the other stars, will appear disposed with tolerable uniformity in different directions. To *him*, our cluster will present the form represented in Fig. 151; and he may perhaps speculate as to the appearance which would be exhibited to *us* by the bright band of stars, which encircles our group, and gives such a pleasing variety to the aspect of our firmament. Most of the resolvable nebulæ have a round or oval aspect;—their loose appendages and irregularities of form being as it were extinguished by the distance, and only the general figure of the more condensed parts being discernible.

537. But there is a very numerous class of nebulous objects,

which cannot be resolved into distinct stars, even with the highest powers which the telescope at present possesses: these are termed *irresolvable* nebulæ. Now, from the regularity of the forms presented by some of these, and from other circumstances, astronomers have generally agreed to consider *them* also as clusters of stars, too far removed for the individuals to be distinguished. The reasonableness of this idea is evident from the fact, that they present appearances precisely resembling those of the resolvable nebulæ, when viewed with inferior telescopes,—such as were the sole instruments of astronomers less than a century ago; and that every improvement in the telescope (and such are continually taking place), enables some or other of them to be *resolved*. To this class we are perhaps to refer the very remarkable nebula shown in the accompanying figure, which seems like a picture or fac-simile of our own system hung up in space, and which has been already employed as an imaginary delineation of it.

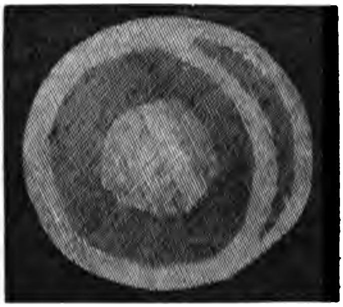

FIG. 154.

538. But it is also certain that a large number of these nebulous patches must have a different character; and that, even if we could view them from a comparatively short distance, we should not be able to distinguish any individual stars among them. One of the most remarkable of these is seen in the constellation Orion, where it occupies the middle part of the Sword. To the unaided eye it appears as a small star, having a somewhat indefinite hazy aspect. With a telescope of low power, it is seen that the light comes from a surface much larger than the mere point of a star; and when more highly magnified, this surface is seen to be of considerable extent and of strange irregular form. Now, the peculiarity of this nebula is its great size and brightness, combined with its complete irresolvableness;

for even with Sir W. Herschel's 40 foot telescope, it did not present the slightest indication of being composed of separate stars. To be thus irresolvable under the most powerful telescope, the stars in this nebula,—supposing it to have a constitution similar to that of the nebulous clusters already described,—must be placed at a distance from us far exceeding that of any of those resolvable nebulæ, and therefore quite inconceivable; and not even a milky light could be sent from it through so vast an interval, unless the stars which compose it were crowded together in a most improbable degree. Hence there can be little doubt, that this appearance results from a vast mass of self-luminous matter, which exists in the condition of a diffused vapour, floating in space, like the most delicate clouds which we distinguish in the flood of light sent upwards in a calm sunset. A similar nebula, also visible to the naked eye, and looking like a faint luminous spot upon the dark-blue of the firmament, may be seen in the Girdle of the constellation Andromeda.

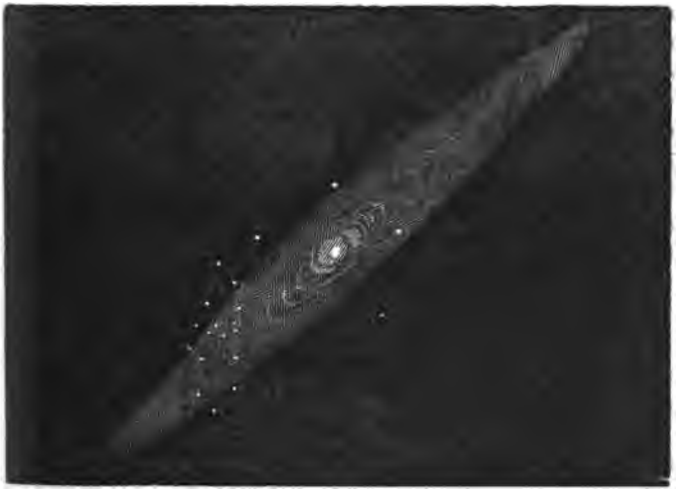

FIG. 155.—NEBULA IN ANDROMEDA.

539. Of the existence of this self-luminous or nebulous

matter, there are many other proofs. Numerous stars exist in the heavens, which do not present the definite appearance of the rest, but are encircled with a halo or dim atmosphere, and yet are evidently nothing else than *stars*,—the body being perfectly distinct in the centre, and the luminous atmosphere being so gradually shaded off, that it is impossible to suppose it to consist of an assemblage of distinct solid masses.' It will be hereafter mentioned (Chap. XXII.) that, between stars having a very extensive atmosphere of this kind, with but an indistinct solid centre, and stars entirely destitute of it, and being (as it were) *all* centre, a regular series of gradations may be detected; which leads to the belief, that these nebulous stars are gradually undergoing a change, by the conversion of the luminous vapour into the solid state, so that the body is continually increasing in bulk, whilst the luminous atmosphere is diminishing in extent: and further, that there is a high degree of probability (to say the least) attendant upon the supposition, that *all* the solid masses, composing our own and other clusters, were originally in the condition of this luminous vapour, or nebulous matter.

540. These unresolved nebulæ, which are suspected to consist of patches of nebulous matter, not condensed into solid masses, are very numerous, and exhibit strange varieties of form. Many, like the nebula in Orion, present a large ill-defined surface, in which it is difficult to say where the centre of the greatest brightness is. Some appear to cling to stars, like wisps of cloud; whilst others exhibit the appearance of enormous rings, with a vacancy more or less complete in the centre. A very remarkable annular (ring-like) nebula, in the constellation Lyra, is described by Sir J. Herschel as having an opening which is not entirely dark, but is filled up with a faint hazy light, resembling fine gauze stretched over a hoop. Another nebula is mentioned by him as possessing the remarkable form of an hour-glass or dumb-bell; the bright matter being surrounded by a thin hazy atmosphere, so that the whole presents an oval form. It appears that double nuclei are not unfrequent, exhibiting all the varieties of distance, position, and relative brightness, with their counterparts the double stars. Now, as

single nebulæ, having a correspondence with these in size and appearance, are but rarely seen, it is extremely improbable that the neighbourhood of two such bodies should be apparent only; and it is still more improbable that they should touch, and in part overlap each other, without having any mutual connection. It is much more likely that they constitute systems, which are perhaps binary stars in process of formation; and they offer most interesting subjects for future inquiry.

541. No certain knowledge can be gained as to the constitution of the nebulæ, and the changes they undergo, until they have been watched through their different aspects during a long period; and in order that this may be accomplished, it is necessary to keep accurate records of their positions and appearances at different times,—a work of immense labour, which is only now begun. No fewer than 2000 nebulæ and clusters of stars were observed by Sir William Herschel, and their places determined by him. His son, Sir J. Herschel, commenced, in 1825, "the arduous and pious task" of revising his father's observations; and he published, in 1833, a list of 2500 nebulæ and clusters, of which 500 were new. Since that time, he has been engaged in the exploration of the Southern Hemisphere; and, when his observations shall have been arranged, a vast amount of novel information will doubtless be made public. To the exalted spirit in which he has undertaken this great work, let the following quotation bear testimony.—"How much is escaping us! How unworthy is it in them who call themselves philosophers, to let these great phenomena of nature—these slow but majestic manifestations of the power and glory of God—glide by unnoticed, and drop out of memory beyond reach of recovery, because we will not take the pains to note them in their unobtrusive and furtive passage,—because we see them in their every-day dress, and mark no sudden change; and conclude that all is dead, because we will not look for signs of life, and that all is uninteresting, because we are not impressed and dazzled."

542. The question naturally presents itself, when the analogy of the Stars and our Sun is considered, whether the latter partakes

of the nebulous character which has been mentioned as being exhibited by many of the former. There is a phenomenon, known under the name of the Zodiacal light, which is now generally regarded as leading to such a conclusion. It consists of a long train of faint light, of a conical form, which is left by the sun after setting, and is projected upwards on the sky. It is easily seen, after almost any clear sunset, in tropical climates; but in our comparatively hazy atmosphere it is not so readily distinguished; and it is only when the sun is in its most favourable position, which happens about the month of April, that it can be clearly seen, and then only on a clear evening. It is called the Zodiacal light, from its following nearly the course of the Ecliptic or sun's path (§. 547). We know that it extends on all sides of the sun; since it may be seen before he rises, as well as after he sets; and from these facts it may be certainly concluded, that it is produced by a thin self-luminous atmosphere surrounding the sun, and spread out, in the direction of his equator, into a lenticular* form, so that the edge of either half of it will appear like a cone. Its extent appears not to be limited by the orbit of Mercury, or even by that of Venus; and its character appears to be precisely that of the nebulous matter already alluded to, in a state of greater condensation. But although we have thus distinct proof that the Sun belongs to the class of nebulous stars, it is equally certain that it would scarcely appear to be surrounded by such a luminous halo, even when viewed from the nearest of the fixed stars with Herschel's largest telescope; since, as already stated, even the 190 millions of miles which make up the diameter of the earth's orbit, constitute a space which would be viewed from the nearest fixed star at an angle of less than a second, which is much less than that exhibited by the nebulous atmosphere of many of the stars. Hence we are justified in believing, that all the stars are surrounded by such an atmosphere, to a greater or less extent, even though we are unable to see the least indication of it;—a circumstance of which the importance will be obvious, when the theory of their formation is considered (Chap. XXII.).

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* That is, like a lens or round disc of glass, convex or bulging on both sides.

543. One more question yet remains. Do our own group, and the clusters and nebulæ which we can see from it, make up the whole of the universe; or are these but a part of a system still more vast? Upon this question we can only speculate; and yet speculation seems justifiable. For, since every improvement of the telescope brings into view nebulæ, which, through their distance and consequent faintness, were previously invisible,—and resolves others, which were previously considered irresolvable, into distinct stars,—it would be evidently absurd to suppose, that the confines of the universe have yet been explored; and scarcely less absurd to imagine, that man, in his present state of being, and with his limited powers, can ever reach them. Now, it is remarkable that these clusters and nebulæ are not by any means uniformly diffused through the heavens, but that they seem to form distinct bands; so that we must regard our own cluster, and its fellows, not as scattered confusedly through space, but as having a certain definite arrangement, that shall give to the whole assemblage a distinct form. If it could be viewed from a distance, therefore,—if the eye could be removed to a point as far beyond the furthest visible nebula, as that nebula is from the most remote on the other side of this vast assemblage,—it would present an appearance corresponding with that of the Magellanic Cloud. May not the wonderful appearance, then, of this filmy spot (§. 535) be due to its similar constitution; and may we not regard it as including within itself numbers of distinct clusters, every one of them composed of vast multitudes of suns and systems like our own?

544. And if this be regarded as probable, who shall venture to assign a number to these vast assemblages, or to say that he has thus measured the length and the breadth, surveyed the height, or fathomed the depth, of ALMIGHTY POWER? Our own planetary system, comprising as it does a sweep of nearly *six thousand millions* of miles in circumference, is but a speck, almost immeasurable on account of its minuteness, when viewed from the nearest of those luminaries which sparkle in our skies, like brilliants studding the dark mantle of night. The whole assemblage of these luminaries, bound together by a common

tie, and encircled by the glowing zone whose distance reduces its brilliance to the soft and gentle light of the Milky Way, constitutes an isolated cluster, which would appear but as a luminous speck in the firmament, when seen from even the nearest of similar groups, and but as a filmy spot, when viewed even with the most powerful telescopes from the more remote. And all these clusters are themselves part of one great system, bound together by common ties, glowing with the same light, their movements regulated by the same laws,—and thus proclaiming to the mind of man the unity of creative design. And how is this conviction strengthened, when we find that even this is not the highest point from which we can survey the universe,—that we can look even beyond that vast system of which we form so insignificant a part, and discern the impress of that same design in what we might almost term a different universe,—so vast must it be,—so completely does it seem isolated from our own! And even this is probably but one out of many, formed upon the same plan, yet each differing from the rest, as this from ours.

545. It has been well said, that truth is often more wonderful than fiction; and that reason may advance, where the imagination dare not follow. So is it here. For what imagination *could* have ventured so bold a flight, if reason had not pointed the way? The philosopher, engaged in searching for the laws which govern the phenomena of nature, and gaining but a glimpse of the uniformity of plan which is to be discovered amidst their countless variety, sees there displayed an order, a beauty, a harmony, a majesty, more glorious than anything which the fictions of the poet can produce,—because *real*. It is, then, the legitimate use, the noblest employment, of our intellectual powers, to apply them to the attainment of those lofty views of the Creator's works, which shall enable us to see them in some measure as He sees them,—to survey them as parts of one vast and harmonious scheme,—instead of looking upon them (as from a less elevated position we are compelled to do) as insulated spots, beautiful in themselves like the oases of the desert, but connected by no plan that embraces them all and affords the guiding clue to their diversified wonders.

546. Is it not thus that we are led to the highest conception of Infinite power, wisdom, and love, of which our finite minds are capable?—POWER, that has filled all space with the creatures of its hand, so endlessly diversified in their structure and mode of existence, that the mind would not be able to follow them through their varieties, were it not for the unity of plan that pervades the whole:—WISDOM, that has arranged that whole with the most consummate harmony and perfection, attaining every end by means that approve themselves, even to our limited comprehension, as the most simple and the best adapted that could be employed:—LOVE, that in all has provided for the greatest amount of happiness and enjoyment of which each living creature is susceptible,—giving to some the pleasures of earthly existence, which, however short-lived and transient in our estimation, are to them the height of felicity,—and to man, whom the Creator hath made in His own likeness, upon whom He hath stamped His own image and superscription, the power of preparing himself to enter upon a state, where, "disencumbered of a thousand obstructions which his present situation throws in his way, endowed with acuter senses and higher faculties, he shall drink deep at that fountain of beneficent wisdom, for which the slight taste obtained on earth has given him so keen a relish."

> "There is a land where everlasting suns
> Shed everlasting brightness,—where the soul
> Drinks from the living streams of love, that roll
> By God's high throne!—Myriads of glorious ones
> Bring their accepted offering! Oh how blest
> To look from this dark prison to that shrine—
> T' inhale one breath of Paradise divine—
> And enter into that eternal rest
> Which waits the sons of God."

"If the eye of man is here permitted to behold such dazzling wonders,—if his mind can soar into such depths of space, and grasp such immensity of time,—what will be the world which *eye* hath not seen, and which the human imagination cannot conceive! What will man be when he is perfected and become as the angels in heaven!"

CHAPTER XVI.

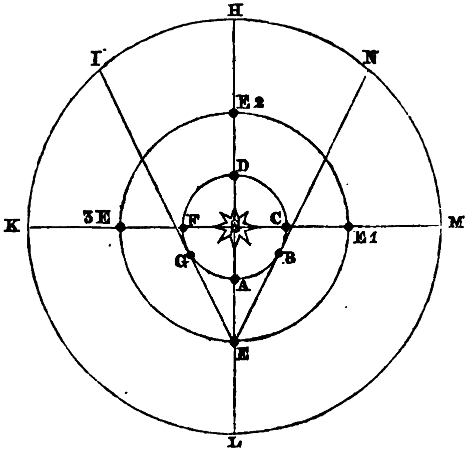
OF THE APPARENT AND REAL MOTIONS OF THE SUN AND PLANETS.

547. Besides their daily rotation around the earth, the Sun and Planets appear to have motions of their own; so that their place among the fixed stars is continually changing. The ancient astronomers were well acquainted with these, so far at least as they could be ascertained by their imperfect instruments of measurement; and they framed an ingenious theory to account for them. The idea of the sun's daily motion around the earth, along with the fixed stars and planets, being once admitted, it was not difficult to suppose that he travels a little more slowly than the stars, so as daily to shift his apparent place among them; by which *he* makes only 365 revolutions round the earth, whilst *they* perform 366 (§. 454). They accounted for this independent motion by imagining, that, whilst the sun is carried round the earth by the general motion of the starry sphere (§. 455), he has a sphere of his own, which travels in the contrary direction, and makes one revolution round the earth in a year. They observed that his path among the fixed stars (determined in the manner already mentioned) is a very regular one, and forms a circle in the starry sphere, which does not correspond to its equator (that is, is not everywhere equally distant from its poles), but is inclined to it, being considerably nearer the north pole in one part of its course, and as much nearer to the south pole in another. This path they called the *Ecliptic;* and they observed that the points where the Ecliptic crosses the Equator (see Fig. 160) are those at which the sun is, when the length of the day and night is equal; whilst the length of the

day is greater (in the part of the globe to the north of the Equator) when the sun is in the northern half of the Ecliptic, at which time he rises higher in the sky; the length of the night being greater whilst he is traversing the southern half of the Ecliptic. The belt of stars above and below the sun's path was termed by them the Zodiac; and it was divided by them into twelve constellations (§. 500), which were termed the *Signs of the Zodiac.* These are,—*Aries* (the Ram), *Taurus* (the Bull) *Gemini* (the Twins), *Cancer* (the Crab), *Leo* (the Lion), *Virgo* (the Virgin), *Libra* (the Scales), *Scorpio* (the Scorpion), *Sagittarius* (the Archer), *Capricornus* (the Goat), *Aquarius* (the Water-bearer), and *Pisces* (the Fishes). The list may, perhaps, be best remembered by the following doggerel lines—

The Ram, the Bull, the heav'nly Twins,
And next the Crab the Lion shines,
  The Virgin and the Scales,
The Scorpion, Archer, and He-Goat,
The Man that holds the Watering-pot,
  And Fish with glittering tails.

548. When the idea of the *daily* revolution of the sun round the earth was abandoned by Copernicus, it was at once perceived by him, that the *annual* motion of the sun was alike improbable; and that his apparent change of place may really be accounted for, quite as satisfactorily, and much more probably, by regarding the sun as fixed, and the earth as revolving



.15.

round him. This may be easily proved. For, in the accompanying figure, let S be the sun, fixed in the centre; and let E, E 1, E 2, and E 3, be four positions of the earth, revolving around him. Now, when the earth is at E, the *apparent* place of the sun in the Ecliptic (which is represented by the outer circle) is found by drawing a line from E through S; and this line, terminating in H, marks this as the position of the sun among the fixed stars. But supposing the earth to travel onwards to E 1, the sun's place, found in the same manner, will be at K. When the earth has advanced to E 2, the sun will have shifted his position to L; as the earth travels onwards to E 3, the sun travels to M; and by the time it has reached its first position E, the sun reaches *its* first position H. Now, if we imagine, with the ancient astronomers, that the earth is at S, and that E, E 1, E 2, E 3, are different positions of the sun, we shall not see any difference in the sun's apparent path among the stars; except that his place at any given time will be in a part of the heavens opposite to that in which he would be seen from the earth, if their positions were as at first described. For, to an observer at S, the sun, when at E, will appear to be at L; when at E 1, he will appear at M; when at E 2, he will appear at H; and when at E 3, he will appear at K. The time and direction of his apparent revolution is the same in either case.—In deciding this question, therefore, we must be influenced by other considerations, such as the relative sizes of the earth and sun, and the analogy of the other planets, which can be proved to move round him; by these it is not left in the least degree doubtful, that the apparent annual revolution of the sun among the stars is caused by a real annual revolution of the earth around him.

549. The apparent paths described by the planets (of which *five* only were known to the ancients, — namely, Mercury, Venus, Mars, Jupiter, and Saturn), do not differ widely from that of the Sun; but they are executed in different times. Thus Mars requires nearly two of our years to perform one complete revolution; Jupiter nearly twelve; and Saturn nearly thirty. Hence it was imagined that each of them was fixed in a different

sphere, which was daily carried round the earth with that of the stars, but which had a contrary movement of its own, like that of the sun. Judging from the times of these movements, they formed a correct idea of the relative distances of these bodies from us. The Moon, whose revolution is performed in a month, they considered to be the nearest; they supposed Mercury to be the next, then Venus, and then the Sun,—their times being less than his; beyond the sun they placed Mars, Jupiter, and Saturn. The planets nearer than the sun were called *inferior;* the more remote, *superior;* and these terms are still employed. But it was soon observed that the motions of the Planets have not the regularity which characterises those of the Sun and Moon; for that, instead of always proceeding onwards in their course among the stars, they sometimes appear stationary, and sometimes actually seem to move backwards for a short time—then becoming stationary again, and afterwards moving forwards again. The ancient astronomers were much perplexed to account for these irregular motions; and invented many ingenious methods of explaining them. They set out upon the principle that all the heavenly bodies move in *circles*,—the circle being considered the most perfect figure; and they endeavoured, by combining together two or more circular movements, to show that the planets might continue to execute these without interruption, whilst appearing to us to move forwards, backwards, or to remain stationary. Into the details of this explanation it is not desirable here to enter, since its falsity has been completely proved; but it may be mentioned, that so complex was the system of motions thus required to account for the irregularities of *each* planet, and so unlikely did it seem that such an apparatus could execute its movements without jarring or disturbance,—that Alphonso, king of Castile, having been instructed in these cumbrous mysteries, is recorded to have said,—"If I had been the Creator of the universe, I could have made it better."—To such low ideas of a creative power and wisdom does a false philosophy lead.

550. The greatest difficulties of the early astronomers re-

spected the planets Mercury and Venus, which are never seen at any great distance from the sun, and seem to vibrate (as it were) within a limited range on either side of him. There are traces in the writings, even of those who believed in the motion of the sun round the earth, of an idea that Mercury and Venus really revolve round the sun, and are carried by him in his annual and daily rotation round the earth. Copernicus saw the truth of this idea; and pointed out that, if combined with the idea of the earth's revolution around the sun, it would reconcile all the principal irregularities observed in their motions. Thus in Fig. 156, let the circle A B C D F G represent the orbit of one of the inferior planets, S being the position of the sun, and E, E 1, E 2, E 3 the orbit of the earth. Now, supposing that, while the earth is at E, the inferior planet, Mercury or Venus, is at A, it will then be in the same line with the sun, so that, if it be seen from the earth, it would occupy a corresponding part, H, of the Ecliptic. It would be invisible to us, however, in consequence of its bright or illuminated face being turned completely away from the earth (§. 553); and instead of being exactly *on* the ecliptic, it would be probably a little above or a little below it. But suppose the planet to be in the position B, it would then be seen at N, or to the west of the sun; it would therefore set before the sun, and also rise before him, being thus a *morning* star. Now, this position is the one in which the planet is most removed from the sun; for it is easy to see that no line can be drawn from E through any point in the circle A B C D F G, which shall diverge from the line E S H passing through the sun, at a wider angle. Supposing the planet, in its progress through its orbit, to advance to D, it will then have returned to the apparent position H; and its motion from N to H, being in the same direction as its real revolution in its orbit, is termed *direct*. Continuing still to revolve round the sun, it comes to G, and is then seen at I; it is then east of the sun, and consequently rises and sets later than the sun, or is an evening star. In its passage through the part G A of its orbit, its apparent place again approaches that of the sun; and its motion among the stars from I to H, being now in the direction contrary to that of its real revolution, is termed *retrograde*. The retrograde movement continues, until the planet reaches B and is seen at N; after which it returns by a direct movement to H, and thence to I.

551. Now, in this description it will be seen that we have not taken account of the earth's motion, and have therefore considered the place of the sun as fixed at H. The vibration of the planet on either side of the sun will be exactly as first represented; but as the sun's place among the stars is itself changing, the inferior planets will go forward (as it were) along with him; and thus, instead of being limited to the small portion I N of the whole ecliptic, they will in time traverse the whole of it,—each retreat being shorter than the advance which precedes and follows it. This will be understood from Fig. 157. For let S represent the sun, as before; let the inner circle represent the orbit of Mercury, the middle circle that of the earth, and the outer circle the ecliptic. The spots E, E 1, E 2, &c. upon the orbit of the earth represent its various positions, corresponding to those of Mercury, which are indicated by the spots 1, 2, 3, &c. upon the inner circle. During the time that the earth moves from E 1 to E 2, Mercury passes from 1 to 2; in the same manner as the earth moves from E 2 to E 3, Mercury passes from 2 to 3; and thus, whilst the earth moves from 1 to 8, Mercury executes a whole revolution, and begins another. Now, when the earth is at E 1 and

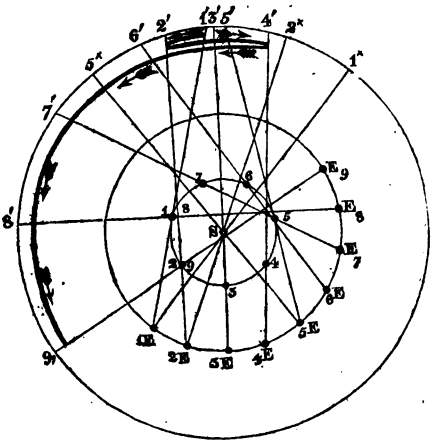


Fig. 157.

Mercury at 1, the place of the latter in the sky will be at 1′ in the outer circle; and as the apparent place of the sun, as viewed from the earth, is at 1 *, we see Mercury at his greatest distance to the east of the sun. But by the time that Mercury has advanced to 2, the earth will have moved to E 2; the apparent movement of Mercury, therefore, will be from 1′ to 2′; and this being in the direction of his real revolution (or from west to east), is a *direct* motion. At the same time, the apparent place of the sun will have changed from 1 * to 2 *; and as his motion is more rapid than that of Mercury, the latter will seem to have approached him. As Mercury advances to 3, the earth advances to E 3; and by this change in their relative positions, there is a change in the apparent position of Mercury from 2′ to 3′; and this movement, being from east to west, is *retrograde*. At the same time, the sun has been regularly advancing in his course, so that his apparent position comes to be the same as that of Mercury, namely 3′; and by this double change Mercury has been gradually approaching the sun, and at last comes into the same line with him, which is termed Mercury's *conjunction*. The retrograde movement of Mercury continues, whilst he is travelling from 3 to 4, the earth at the same time changing its place from E 3 to E 4; and as the sun continues to move steadily in the opposite direction, they again begin in appearance to separate from one another, Mercury being now, however, to the *westward* of the sun. When Mercury has reached 5, he will be seen at 5′, having commenced his return or *direct* movement; and the sun, as seen from the earth at E 5, will have the apparent place 5 *; so that Mercury is now at his greatest distance on the western side of the sun. His direct movement continues, as he passes through the positions 6, 7, 8, whilst the earth changes to E 6, E 7, and E 8; when at 8, he really attains the point from which he started; but he is seen in a very different place among the stars, in consequence of the changed position of the earth. During this movement, the sun also continues to change his position in the ecliptic, in the same direction; but Mercury's apparent motion is quicker; so that when Mercury reaches 9, he is seen at 9′, which is almost exactly the same point at which the sun would be seen from the earth at E 9. Hence Mercury is again in *conjunction*, though he is on the side contrary to his previous one, where he was between the earth and the sun. By a continuation of the same change, we should find that Mercury, still gaining in his apparent motion upon the sun, will again become east of him, and will afterwards commence a retrograde movement, which will soon give place to a direct one, as before. The path through which we have traced Mercury is indicated by the bent line drawn within the outer circle.

552. Now, by applying the same mode of reasoning to the superior planets, Copernicus showed that *their* apparent irregularities could be accounted for as simply. For in the accompanying figure, let S, as before, represent the sun, and E, E 1, E 2, &c. the various positions of the earth; whilst P, P 1, P 2, &c. represent the corresponding positions of Mars or Jupiter, moving more slowly in a larger orbit. It will be seen that the apparent places of the planet as seen from the earth, will be those indicated on the outer circle or ecliptic by P′, P′ 1, P′ 2, &c.; and that it thus performs a movement which is *retrograde* between P′ 2 and P 3, and *direct* elsewhere. The extent and rapidity of the retrograde movement are greater, as the distance of the planet from the earth is less; hence it is more remarkable in Mars than in Jupiter, and in Jupiter than in Saturn. The superior planets are not confined to the neighbourhood of the sun, however, as Mercury and Venus are; but are sometimes seen in a part of the heavens exactly opposite to him. Thus suppose A, Fig. 156, to be the position of the earth, and E

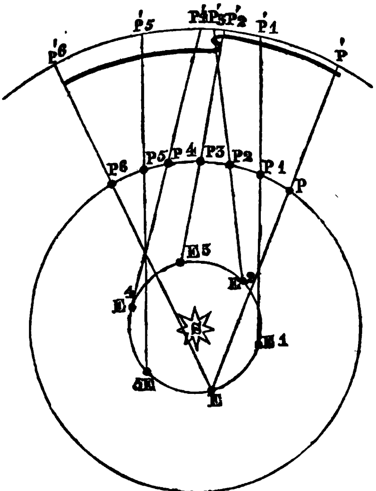


FIG. 158.

to be that of Mars or Jupiter, the sun will be seen at H, whilst Mars or Jupiter is seen at L. It is then said to be in *opposition.*

553. The doctrine of the earth's double motion, long after it was first propounded by Copernicus, was strenuously opposed by those who called themselves philosophers. Some of the objections brought against it were of a nature which, in the present day, we should consider as most absurd. But there was one which seemed more important, even to Copernicus himself. This was the supposed fact, that Mercury and Venus always present to us round and fully illuminated discs; whereas, if they revolve round the sun, in the manner supposed by Copernicus, and derive their light from him, they ought to present a series of *phases* or changes of appearance, resembling those exhibited by the moon. Thus in the accompanying diagram, let E be the position of the earth, and let V 1, V 2, V 3, &c. be various positions of the planet Venus in her revolution round the sun. The dark portion of each small circle shows that part of the planet which, not being illuminated by the sun, is invisible to us; whilst the unshaded portion shows that which is illuminated, and of which we shall see more or less according to our position. The lines drawn across these circles show the boundary of the portion of the planet's globe, that is seen from our earth at E. Now, when Venus is at V 1, the whole of her illuminated side is turned directly towards the earth, and her disc should be round, like that of the moon at full. As she passes towards V 2, V 3, and V 4, however, we gradually see less and less of her illuminated side; and she should appear at first gibbous, then a half-circle, and then horned, just as the moon does. When she arrives at V 5, her dark

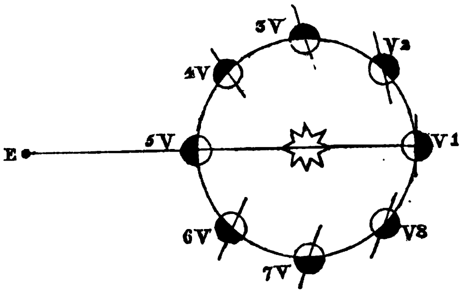


Fig. 159.

side is entirely turned towards us, and she should then be completely invisible; but she should reappear, on the other side of the sun, in a form like that of the new moon, and should go through a series of changes resembling hers, until she again arrives at the full.

554. Now, all this, to any one who gives attention to the subject, is a necessary consequence of the system of Copernicus; and so far from attempting to dispute the fact, he contented himself with replying, that it would be perceived to be so, if ever we had the means of seeing the discs of these planets more clearly. His prediction was most signally confirmed; for soon after his death the telescope was invented; and one of the first astronomical discoveries made with it, was that very series of phases, the supposed absence of which had been the most important objection to his doctrine, but which thus afforded to it them ost triumphant confirmation. It is only during a part of the revolution of Venus, however, that these phases can be observed; for when she approaches the sun too nearly, she is drowned (as it were) in his flood of light, and her form cannot be distinguished. This is still more the case with Mercury; whose apparent distance from the sun is never so great as that of Venus, the orbit in which he moves being much narrower.

555. The doctrine of Copernicus thus gradually prevailed, and its simplicity came to be appreciated. An attempt was made by Tycho Brahe, an eminent Danish astronomer, to combine the idea of Copernicus with the ancient system; by supposing that the earth remains fixed in the centre of the system, and that the planets revolve, not round it, but round the sun, and are thus carried with him in his annual course round the earth. This idea never extensively gained credit, however; and it seems to have been only adopted by Tycho Brahe, because he perceived the impossibility of accounting for the motions of the planets upon the ancient system, and yet was not prepared to give it up for the simple doctrine of Copernicus—*his* mind, like that of other less enlightened men of the time, being imbued with the idea of the earth's fixity, to question which seemed to be striking at the root of all knowledge.

556. It is evident, from what has been said, that all the irregularities of the apparent motions of the planets are thus explained by the simple idea of their revolution round the sun, combined with the motion of the earth; and that, instead of the cumbrous machinery with which the ancient astronomers were obliged to suppose every part of their system to be loaded, we can view it with Copernicus, as a simple but majestic whole. By carefully observing the places of the planets, as seen from the earth, we can determine those in which they would be seen from the sun, with as much accuracy as if we were ourselves really viewing them from the centre of the whole system; and can thus appreciate the real uniformity of their revolutions, and the simplicity of the principle by which these are governed.

557. A more striking analogy has scarcely ever, perhaps, been pointed out, between the changes in the world of matter and in the world of mind, than that which the profound and excellent Hartley has suggested, between the movements of the solar system, as viewed by the terrestrial astronomer, and the operations of God's moral government, as it manifests itself to our present imperfect observation. There is no thinking person, it may probably be affirmed, who has not at some time or other found it difficult to reconcile with his idea of the infinite benevolence of the Deity, the pain, guilt, and wretchedness, which he sees in the world around him;—who has not felt disposed to murmur or repine at the dispensations of Providence, as they affect himself, or those in whom he feels the deepest interest;—or who has not experienced some despondency, when the best-laid schemes (as they appeared), designed by motives of pure benevolence, to promote the welfare of the human race, have proved abortive, and the social condition of the world has appeared rather to be retrograding than progressing. Those who have learned, by the study of astronomy, how from a perplexing and imperfect, because a distorted view, a system replete with beauty and harmony may be discovered, simply by placing ourselves in its centre, and viewing every movement as it would be *there* seen, should attempt to carry the same idea into their contemplations of the more obscure and difficult scheme of God's

moral government. "We ought," as Hartley finely observes, "to suppose ourselves in the centre of the system; and to try, as far as we are able, to reduce all apparent retrogradations to real progressions."

558. And those who have most calmly watched, and most quietly waited, for the appointments of Providence, have testified most abundantly that such is the actual result of experience,—that out of darkness has shone marvellous light,—that out of perplexity a straight path has been revealed,—that out of the guilt or misery of the few have arisen the elements of happiness to many,—and that out of the apparent retrogradations in the condition of mankind, have sprung the elements of its most rapid progressions. By dwelling on such views, the mind becomes habituated to them; and that entire conviction of the perfect benevolence of the Deity is obtained, which leads to an implicit reliance on his paternal goodness, even in the seasons of greatest darkness and despondency. "And thus," continues Hartley, "all difficulties relating to the Divine attributes will be taken away; God will be infinitely powerful, knowing, and good, in the most absolute sense, if we consider things as they appear to Him. It is the greatest satisfaction to the mind, thus to approximate to its first conceptions concerning the Divine goodness, and to answer that endless question,—why not less misery and more happiness?—in a language which is plainly analogous to all other authentic language, though it cannot yet be felt by us, on account of our present imperfection, and of the mixture of our good with evil."

559. The same idea may be carried out in the formation of our own rules of conduct. "With respect to benevolence, or the love of our neighbour," says Hartley, "it may be observed that this can never be free from selfishness, till we take our stand in the Divine Nature, and view everything from thence, and in the relation which it bears to God. If the relation which it bears to ourselves be made the point of view, our prospect must be narrow, and the appearance of what we see, distorted."

Inclination of the Orbits of the Planets.

560. From what has been stated of the cause of the sun's apparent path among the stars, it will be evident that the Ecliptic is that circle in the starry sphere, in which the earth would appear to move, if seen from the sun; and that a plane or level surface, passed through the earth's orbit, and carried out indefinitely, would reach this line. Now it has also been mentioned, that the planets do not move exactly through the same path with the sun, but are sometimes a little above it, and sometimes below. The reason of this is, that their orbits are not upon the same plane or level with that of the earth, but are more or less *inclined* to it. The meaning of this term is shown in the accompanying figure, which represents the orbits of two planets revolving round the sun, and viewed *aslant*, that their relative positions may be better seen. Let A E B F represent the ecliptic, or orbit of the earth; whilst *c e d f* represents the orbit of Mercury or Venus, the end *c* being raised considerably above the plane or level of the earth's orbit, whilst the end *d* dips as much below it, the points *e* and *f* being on the same level. Their relative positions will be better understood, by carrying out the orbit *c e d f*, until it becomes as large as the other; and it will then be represented by C E D F. Thus it is seen that the plane of one orbit cuts the plane of the other in the line E *e* S *f* F; this line always passes through the centre. The angle which the two planes make with each other, is called the *inclination*. Correctly speaking, either orbit might be said to be inclined to the other; but it is convenient to refer all of them to that of the Earth as a common standard. Hence the inclinations of the orbits of the different planets are expressed in reference to the Ecliptic.

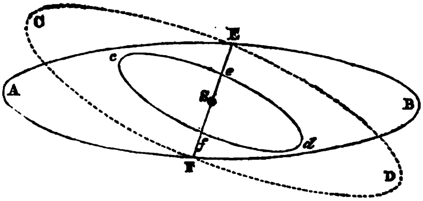


FIG. 160.

561. As it is only at the two points, *e* and *f*, that the plane

of one orbit is the same with that of the other, so it is only when the two planets happen to be at the same time on these corresponding points of their respective orbits, that they will actually come into the same line. For suppose the earth to be at B, whilst Mercury is at *d*, he will be seen from the earth not *upon* the sun, but *below* him, though in the same part of the ecliptic. Or, again, let the earth be at A, and Mercury at *c*, he will then be seen *above* the sun, though in the same part of the ecliptic. And when the planet is on the other side of the sun, as at *c* when the earth is B, or at *d* when the earth is at A, it will not be hidden behind the sun, but will be seen above or below him. But when the earth is at or near one of the points E or F, and Mercury is also at or near one of the points *e* or *f*, (which are called the *nodes* of his orbit,) he will either be seen as a black spot upon the sun's disk, or will be obscured behind it, according as he is between the earth and sun, or beyond the latter. The apparent passage of Mercury or Venus over the sun's disk, which is called a *transit*, is obviously a phenomenon that can occur but rarely; since many revolutions of both may happen, before they will be at or near the nodes together. It is obvious that no *transits* of the superior planets can occur; but the earth, being an inferior planet to Mars, Jupiter, &c., will perform occasional transits to *them*.

CHAPTER XVII.

OF THE LAWS GOVERNING THE MOVEMENTS OF THE BODIES COMPOSING THE SOLAR SYSTEM.

562. "WHAT is a law of nature?"—is a question which may be appropriately put, at the commencement of the exposition, to which we have next to proceed, of those governing principles whose operation we trace in the movements of the heavenly bodies. Yet the answer to it will be best given, after we have traced the steps by which these principles have been attained. By those who watched these movements, it was early perceived that an order and regularity prevail among them. The uniform motions of the Stars, which vary only in the times of their rising and setting, with the place of the sun among them, must have been remarked in the very earliest times. The Sun daily rises in the east, and sets in the west; his path through the heavens, though altered in each succeeding circuit, is yet but a repetition of that which he took a twelvemonth previously; and we may predict with certainty, that it will be traversed with the same exactitude, at every future return of the same season. Though the "changes of the Moon" have passed into a proverb, yet in these variations is the influence of law and order yet more obvious,—so exactly do they recur, with such positiveness may they be predicted. Even the less frequent phenomena which are dependent upon some of the finer peculiarities of her motion, and which seem to occur with no regularity—those, for instance, of eclipses—are reduced, by patient and long-continued observation, to a code of no inferior certainty; so that even the Chaldean shepherds, who were completely ignorant of the mode in which they were regulated, were enabled to predict them, for a

long series of years beforehand, with considerable accuracy. So, again, with regard to the movements of the Planets:—although many apparent irregularities exist, which, with the wrong conception formerly entertained in regard to the central position of the earth, gave rise to great difficulty, yet in all ages there has been a settled idea, that they are capable of being accounted for on fixed and determinate principles. Even Comets—those strange and wandering lustres, which seem almost to connect our system with the universe beyond—were not altogether excluded from this idea of regularity, by the more sagacious of the earlier astronomers; although regarded by the vulgar but as portents of the Divine wrath, significant of war, pestilence, or famine.

563. More attentive observation of these movements led, as we have seen, to a clearer and more accurate conception of the mode in which they take place. The earth, by the followers of Copernicus, was no longer regarded as the centre of the system, but as one of its subordinates; and the simple idea that the planets, instead of revolving around the earth, move, like her, around the sun, was sufficient to explain a large number of the apparent irregularities, and to increase the belief in the simplicity of the laws by which the movements are controlled. For this idea once properly applied, showed that, however regular and exact the movements of the planets around the sun, they *must* present irregularities when viewed from a body which, like our earth, is itself out of the centre of the system. But Copernicus still entertained the idea that the heavenly bodies move in circles, and at a uniform rate; and he could not satisfactorily account for certain irregularities which presented themselves, after all needful allowance had been made for the difference between real and apparent motion. The discovery of the cause of these was reserved for Kepler, who had early imbibed the doctrines of Copernicus, and who devoted the energies of his powerful mind to the search for the laws governing the planetary motions.

Kepler's Laws.

564. After many ingenious speculations, which he abandoned when they were proved to be erroneous, as easily as he

had constructed them (a rare virtue in a philosopher, but that which every one ought to possess), Kepler became acquainted with the mass of valuable observations which had been collected by Tycho Brahe; and selecting from them those which related to the planet Mars, he applied himself with the greatest diligence to discover his true orbit, or the path he describes in space around the sun. His perseverance was crowned with success; for, after a patient and laborious investigation, he succeeded in proving that, if we regard the orbit of Mars as an *ellipse* or oval, instead of a circle, we shall be able to account for *all* the variations in its observed positions. Extending the same mode of inquiry to the orbits of the other planets, Kepler showed that they also are elliptical; and so far as the orbits of their satellites have been investigated, the same rule holds good in regard to them. It might have been predicted, then, with tolerable certainty, that all planets move round the sun, and all satellites round their primaries, in obedience to this law; and it has been found to hold good most completely, in regard to the five new planets, and the numerous satellites, discovered since the time of Kepler. But he could only state the general fact, without assigning any reason for it; and we shall find that it was reserved for Newton to give that proof of the necessity of this form of the orbit, as the result of the primary laws of motion, which alone could properly confer upon it the character of a general principle.

565. The forms of the orbits of most of the planets depart little from that of the circle; that is to say, although elliptical or oval, yet the oval is not a long one—or, in other words, its eccentricity is not great. The orbits of the comets, on the other hand, are extremely long ellipses; and thus we have, as it were, two extremes in the form of the paths of bodies belonging to the solar system, in each of which the same law holds good. The place of the Sun, in all these cases, is not in the *centre* of the ellipse (C, Fig. 161) which is the point where its longest and shortest diameters, P P 6 and A B, cut each other; but in one of the points, S, F, which are termed the *foci*. Hence in a very elliptical orbit, the sun will be much nearer one extremity than

the other; and even in an ellipse so little eccentric as that of the earth's orbit, the variation between the least and greatest distances (S P and S P 6) is no less than three millions of miles. The *mean* distance, which is the one usually referred to when the distance of a planet from the sun is mentioned, is the average between the longest and shortest, and would be represented by the line S B, Fig. 161; which, by a property of the ellipse, is equal to half the long diameter.

566. It was found, however, by Kepler, that although the *places* of the planets could be thus exactly accounted for, and their courses predicted, there was an irregularity in their *times* of movement, which was inconsistent with the idea of their having an equal velocity in different parts of their orbit. He observed that, when in the part nearest the sun, they moved with much greater rapidity than when at their greatest distance; and that, after passing their *perihelion** or nearest point, their motion was gradually retarded until they reached the *aphelion*† or furthest point; after passing which it was gradually accelerated until the perihelion was again reached. Kepler then applied himself most diligently to discover what general principle might be found to govern these varieties of movement; and his perseverance was again rewarded with complete success. The law which he ascertained to govern the rate of motion of every planet in every part of its orbit, and which has been since found applicable to those newly-discovered planets whose orbits present such varieties of form as completely to test its accuracy,—and not only to these, but to comets moving in orbits far more eccentric,—is extremely simple, and may be thus very briefly expressed in mathematical language:—*The radius vector moves over equal areas in equal times.* To the readers of this treatise, however, an explanation of this law, as well as a simple statement of it, is necessary; and it will, it is hoped, be readily comprehended by the aid of the accompanying diagram, which represents an ellipse more eccentric than the orbits of most of the planets. Of this ellipse, S is one of the foci; and it consequently repre-

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* From two Greek words, meaning *near* the *sun*.

† From two Greek words, meaning *away from* the *sun*.

sents the position of the sun. Each of the lines S P, S P 1, S P 2, &c. drawn from S to points in the ellipse, is termed a *radius vector*. By these lines, the whole area or surface of the ellipse is divided into smaller portions, each bounded by two straight lines and a part of the curve. Now these lines are so drawn in the diagram, that the area included between the lines S P and S P 1 is exactly equal to that included between S P 1 and S P 2; although the distance along the curve P 1 P 2 is much less than the distance P P 1. In like manner, the area bounded by S P 2 and S P 3 is equal to that bounded by S P 1 and S P 2; and thus, in fact, all the areas into which the ellipse is so divided are equal to each other. The portion of the curve which forms their exterior boundary, gradually decreases from P P 1 to P 5, P 6, in proportion to its distance from the centre.

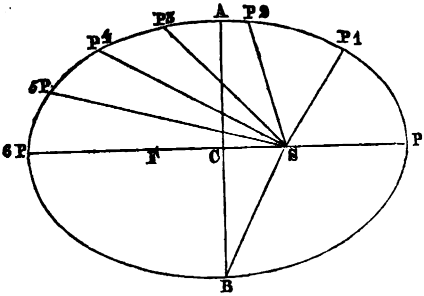

Fig. 161.

567. Into whatever number of equal areas the ellipse be thus divided, the general law holds good, that the planet will move along the portions of the curve that include them, in equal times; so that it moves very much faster when near the sun, than when at a distance from him. If a *circle* were similarly divided into equal areas, as all the radii are equal, these areas would be enclosed by equal portions of the curve; and the motion of the planet would be uniform. The more eccentric the ellipse, therefore, the greater will be the difference in the rate of the revolving body's motion at its two extremities. This difference is most extraordinary, however, in the movement of comets, as will be pointed out hereafter (Chap. XIX.). Now this principle is briefly but fully expressed in the law just stated. For if we suppose the *radius vector*, S P, to move round S as a centre, so as to come successively into the positions S P 1, S P 2, &c. this line will

move over equal areas; whilst the revolving body is moving in equal times through the arcs P P 1, P 1 P 2, P 2 P 3, &c. Or, to state it in another form,—if we mark upon the planet's orbit the portions which it has described in any given times, as, for instance, a day, a week, or a month,—and then draw lines from those points to the focus, we shall find that the included areas are uniformly equal. Thus we see that the apparent irregularities in the rate of movement, are really obedient to a law as constant and regular in its action, as if the body moved at the same rate in every part of its orbit. This law, as ascertained by Kepler, however, is simply the expression of the general fact,—that the rate of movement always corresponds with the area traversed by the radius vector: and *why* this peculiar relation exists, was altogether unknown to him. This it was reserved for Newton to explain.

568. The third great law established by Kepler, is that which governs the times of the revolution of the planets round the sun. Many attempts had been made, both by him and by others, to discover some connection. It was felt to be probable that some relation does exist between the distances of the planets from the sun, and the times of their revolution; since these times increase in the same order as the distances increase, without any exception. These times, however, do not increase in the same proportion with the distance, but in a higher one; thus Venus is at nearly double Mercury's distance from the sun, and her year is almost three times as long; and nearly the same is the case in regard to the planets Saturn and Uranus at the opposite end of the series. But still the proportion is not a simple one, as that of 2 to 1, 3 to 2, or any numbers of such a kind; and after many efforts, Kepler perceived that the relation was as follows:—*The squares of the times in which the planets revolve round the sun, are proportional to the cubes of their mean distances from the centre.* This will be best explained by an example. The mean distance of Jupiter from the sun is almost exactly 5·2 (or $5\frac{1}{5}$) times that of the earth; consequently, reckoning the latter as 1, the *cubes* of their *mean distances* will be as (5·2 × 5·2 × 5·2 =) 140·6 to (1 × 1 × 1 =) 1. Now, the very same

proportion exists between the *squares* of their *times*. The length of Jupiter's year, reckoning ours as 1, is 11·86; consequently, the square of Jupiter's time is (11·86 × 11·86 =) 140·6, whilst that of the earth is (1 × 1 =) 1. In this way, then, we may ascertain the time of a planet's revolution, from the knowledge of its distance; or its distance from a knowledge of its time: and such is the method employed for exactly ascertaining the comparative distances of the planets, which could not be determined with near so much precision by direct observation. Thus, if we know that the period of Jupiter's revolution is 11·86 times that of the earth, we square that number, and take the cube-root of the product (140·6). This cube-root (5·2) gives its proportion of distance to the earth's. In the same manner, if, having the proportional distance, we had desired to find the time of revolution, we cube the distance (5·2); and of the cube (140·6) we take the square-root (11·86), which gives the proportional time. We cannot ascertain their *actual* distances from the sun, without being first acquainted with that of the earth; and this is determined by observing certain celestial phenomena, as already explained (§. 513).

569. These three laws regulating the motion of the planets round the sun,—1. Their motion in elliptical orbits, the place of the sun being in one of the foci,—2. The passage of the radius vector over equal areas in equal times,—3. The constant proportion between the squares of the times of revolution, and the cubes of the mean distances,—are universally known as the laws of Kepler, by whom they were discovered; and every succeeding discovery has only served to show their exact application to new cases, and therefore to prove their correctness. Still, however, they are in themselves only general statements of facts. The reason why such a proportion should exist between the time and the distance, was no more evident than the reason why the planet should move in an ellipse; which seemed a figure much less natural than the circle for it to revolve in. Nor did any connexion appear to exist between these laws themselves. Each expressed one set of facts; and this might or might not have a bearing on the others. It was reserved for Newton, however,

to show that these laws are themselves subordinate to one general principle ; and that all the facts which they express are the necessary results of this.

Newton's Discoveries.—Laws of Motion and Gravitation.

570. Newton commenced the study of the planetary motions, by starting with the idea of their being produced by the combined action of two forces acting on one another in the same manner as they would act at the surface of the earth. By carrying out this idea, he proved that, if a body be put in motion in a straight line, and be then subject to a constantly-operating force, drawing it in a different direction, it will be bent from its straight path towards the source of this second force ; and that, if the two forces be in a certain proportion, the body will revolve around that point. The laws of force and motion, together with this particular application of them, having been already treated of in this volume (Chap VI.), it is not requisite to do more here than refer to them. Now when these principles were applied, by the aid of mathematics, to the planetary movements, it was found that an *ellipse* would be almost necessarily the curve performed by one body revolving round another (§. 172);—that a body moving in such an ellipse must have a very different rate in different parts of its orbit, in consequence of the varying force exercised over it by the central body ;—that this rate always corresponds with the area passed over by the radius vector ;—and lastly, that the diminution of the central attraction as the distance increases, would occasion that particular relation between the distances of the planets and their times of revolution, which has been just explained.

571. Thus the movements of the heavenly bodies, under the influence of these two forces, were shown to be perfectly conformable to those of a body at the earth's surface, acted on by corresponding forces ; and the *laws of motion* laid down by Newton, were proved to apply alike to the movements of the planets in their vast orbits, and to the simplest and most ordinary changes that are continually taking place under our own notice. This, therefore, was a vast advance in *generalization ;* for these

simple principles, when carried into operation, are found to govern *all* the varieties of motion that we can detect, whether in the heavens or on the earth; and thus, whilst each of Kepler's laws embraced a limited group of facts, having little or no apparent connexion with each other, the comprehensive principles established by Newton enabled him to show *why* these laws should exist, or, in other words, to prove that, from the very nature of his principles, the movements *must* take place as Kepler discovered them to do.

572. But there was still another great advance to be made. Newton's reasoning, up to this point, was carried out upon the idea that there exists in the sun an attractive force, which has the power to draw the planetary bodies from the straight paths in which they would otherwise be moving, and to cause them to revolve around him; and he perceived that, if this force be regarded as diminishing in exact proportion to the increase of the square of the distance, it would produce all the results which actually follow. But the question next arose in his mind,—What is the nature of this attractive force?—has it any relation with the attractive force by which the earth draws towards its centre the bodies on its surface? Such an enquiry it would not be difficult to answer satisfactorily, by comparing the force with which the earth attracts a body on its surface, with that with which it draws the moon out of its straight course. Thus, in the accompanying diagram, let E be the centre of the earth, and B C a portion of its surface. Let M O P be a part of the orbit of the moon; and let us suppose that she passes through the space M O in the course of a minute. This shows, upon the principle already laid down in regard to elliptical motion (§. 172), that, if the moon had been allowed to fall freely towards the earth from the point M, she would traverse the distance M N in precisely the same time; and we

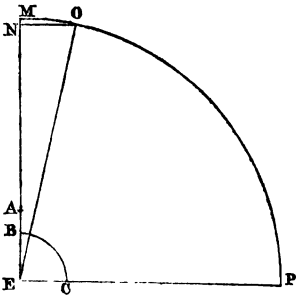

FIG. 162.

are thus enabled to estimate precisely the influence of the earth's attractive force upon the moon, if we are acquainted with her distance, and the consequent size of the ellipse she traverses, so that we may ascertain the precise length of M N. This attraction we may compare with that which the earth has for a body at its surface, by ascertaining the height, A B, through which a body would fall in the time occupied by the moon to fall from M to N, which we have supposed to be a minute.

573. Now the attraction of the earth for bodies upon its surface, would be much greater than for the moon, in consequence of the increased distance of the latter (§. 89); and allowance must be made for this, in comparing the two. If, when this has been done, we find that the amount of attraction which the earth has for the moon, evidenced by its drawing that body out of its straight course to the amount of the distance M N in every minute, is *the same* as that which it has for bodies upon its surface,—we may reasonably conclude that the force is the same in both instances, and not only in these cases, but in all similar ones. Thus, to identify the mysterious force which binds together the far-distant masses of the solar system, with that which produces the simplest and most familiar effects upon the earth's surface,—is an idea which now seems to us simple and familiar; and we may feel surprised that it should have remained so long undiscovered. But it must be remembered that the minds of men had been possessed with the notion, that *celestial* and *terrestrial* motions were of entirely different characters, not governed by the same laws, and dependent on different causes. In fact, when Newton first brought forward his doctrine, it was strongly opposed by all but a very few, who had sagacity to perceive its truth, and appreciate its beauty.

574. The history of the discovery is not a little interesting. After Newton had been engaged in studying the planetary movements, and had discovered that they are to be accounted for by the laws of motion which he had established, he retired to his country-seat, there to meditate upon further progress. It is commonly believed that the grand idea, upon which his fame rests and ever will rest until time shall be no more,—that

of the identity between the attracting power which the earth has for the moon, and that which it has for every particle of matter on its surface,—was suggested to him by the fall of an apple to the ground, while he was sitting in his orchard. But though such an accident may have suggested it to *his* mind, it is probable that in no other human being of his time would this or any other accident have aroused the thought; and it is equally probable that it would have sooner or later occurred to him, if this accident had never happened. For it was not one of those extraordinary phenomena which arrest the attention and strongly excite the spirit of enquiry; but one of a kind which has been, from the very creation of the human race, constantly occurring beneath their eyes, without ever opening the least glimpse of the great truth beyond.

575. When Newton, in the year 1665, first brought the truth of this idea to the test, by comparing the earth's attractive force, exercised at the distance of the moon, with the power it exerts on the surface of the earth, he was led into error by having wrong materials to work upon. It was necessary that he should compare the respective distances of the moon, and of a body on the surface of the earth, from the centre of the latter (§.92); and if either of these distances was wrongly estimated, there would be a disagreement in the results. Now at that time, a *degree* of latitude was reckoned at only 60 miles instead of 69½; and consequently the distance from the centre of the earth to its surface was supposed to be only about 3436 miles, instead of 3964. Hence the result of the calculation was to indicate, that the diminution of the earth's attraction at the distance of 237,000 miles (the mean distance of the moon) was greater by about one-sixth than it really is; and it appeared, therefore, that it is not sufficient to produce such an effect upon the moon as was indicated through observation, by the amount of this difference. Many persons would have imagined that this very close accordance—for such it really is—was sufficient to prove the correctness of the idea; but it was not so with Newton; and he laid his hypothesis aside for nearly *sixteen* years. No advance was therefore made, until 1682; when he accidentally heard, whilst

attending a meeting of the Royal Society, of a new measurement of the length of the degree, which had been made in France three years previously. Having taken a note of the result, and calculated the earth's radius from it, he resumed his former calculation; and it is recorded that, as he advanced towards the completion of his task, and perceived that the result would be probably conformable to his theory,—"when he felt on the verge of obtaining one of the most important laws ever revealed to man, and was recognizing that which for evermore would bind the heavens to the earth, and constitute himself the first of philosophers,—he became so agitated that he could not carry on the computation, but paced the room whilst a friend put the finishing stroke to it." The principle once recognized in regard to the attraction of the earth and moon, its application to the sun and planets was obvious; and thus combining the celestial and terrestrial phenomena into one grand but simple generalization, Newton announced to the world the most important principle that man has ever attained,—that principle which has been already stated (§. 88) as the *law of gravitation* or *universal attraction*. What were his emotions when he first ventured to assure himself of his success, we can only guess at; but from the habitually religious character of his mind, we may infer that they were those of "a thankful child, bending in reverential gratitude, that he had been enabled to look into the ways of the beneficent Maker and Father of all."

576. We are now prepared, therefore, to reply to the question—"What is a Law of Nature?" It has been shown that the majestic phenomena presented to us in the varied movements and changing appearances of the heavenly bodies, take place in a certain order, so definite and constant that they are all capable of being exactly predicted, yet not by any means apparent at first sight. We have seen that, for some of these phenomena, a certain rule or principle might be laid down, whilst another rule or principle might be said to govern others. Now, if we could discover no higher or more general principle, of which these become the necessary results, we should consider these as *immediately* depending upon the will of the Creator, and therefore as primary or fundamental laws of nature. But

by the discoveries of Newton, they were shown to be subordinate laws, resulting from this grand principle of universal attraction, and from the general laws of motion. In these we at present rest, as the highest laws yet discovered;—that is to say, they explain all the varieties of motion, shown by *masses* of matter, with which we are acquainted, and leave nothing to be accounted for. Whether this principle may be united with those which regulate the movements of *particles* of matter, producing the various *molecular* changes which occur in electrical and chemical action, so that one principle still more general may include the whole,—is a question at present undetermined. The simplicity of the mode in which the Creator executes His operations upon the universe, as manifested in the principles or laws discovered by Newton, would lead to the belief that there are other laws yet more simple and comprehensive, which it is perhaps left for another Newton to discover.

577. Our minds, however, must be at present content to rest in the laws of motion and attraction discovered by that illustrious man, as the simplest and most direct expressions we possess, of the mode in which the Deity operates upon the material universe. A law of nature is nothing else than such an expression. When we say that the Creator *willed* that all masses of matter should attract one another, with forces directly proportional to their bulks, and inversely as the squares of their distances,—we not only state that one fact, but include all the consequences of it, however numerous and diverse they may be. Thus we are able to calculate from it the precise force with which the earth attracts a stone upon its surface, and is itself attracted by the sun, the moon, and the planets. And when we state that a mass of matter in motion, will continue moving at the same rate, unless retarded or accelerated by some force external to itself, we do in fact state what is true of every motion in the universe, because the Creator *wills* that it should be so. A law of nature, then, is nothing else than a simple expression of the will of the Divine Creator. Or, to define it in another way, it is the mode in which He determined that the operations of the material universe should be performed. When He created mat-

ter, He endowed it with certain properties, which occasion its various actions; thus he gave it the property of mutual attraction, which causes any two masses to approach each other, if they are not kept asunder by any other force. Having once ordained these conditions, and having foreseen by His infinite wisdom *all* the actions to which they will lead, he continues to act in the same manner. Were he continually changing his plan of operation, we should not be able to avoid the idea of mutability, and therefore of imperfection. In his *moral* government of the world, such changes *may* seem to occur. It requires an enlarged mind, capable of placing itself in some degree in the same position with the Deity, and of viewing things as He views them (§. 557),—such a mind as we sometimes see in the closing years of those who have spent their whole lives in faith and duty, when the world is gradually fading from view, and the spirit seems already preparing to quit its earthly tenement and to enter its immortal home,—to conceive the unity of the design upon which *that* is conducted. And it is perhaps not one of the least advantages of the study of Astronomy, that it impresses on us, more strongly perhaps than the study of any other science can do, the idea of the immutability and perfection of the Divine Mind; and thus prepares us to believe that of which Revelation assures us, in regard to his dealings with mankind.*

578. There is, perhaps, a danger in dwelling too exclusively on these *laws*, lest we should forget that, after all, they are only expressions of the mode in which the Creator is *constantly* acting on the universe. This tendency has shown itself among philosophers in all ages. It is sufficient, say they, to suppose matter endowed with certain properties, for us to account for all its actions. This is quite true so far as it goes: but whence the properties? whence matter itself? *Their* existence cannot be satisfactorily accounted for, except by regarding them as dependent upon the will of the Creator. And if that will underwent a change,—if the supporting, guiding, and controlling hand were withdrawn but for an instant,—the whole fabric of the universe must fall into confusion. We may illustrate this by

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* For some interesting views on this subject, see Mr. Whewell's Bridgewater Treatise, p. 381.

the analogy of the government and laws of a human kingdom; but it must be recollected that the word *law* is here used in a very different sense, being merely a rule of action, to which its subjects are expected to conform, and for violation of which there are certain penalties. The action is not necessarily obedient to the law, but becomes so by the choice of the individual subject. Still there is this important analogy:—The law is made by a government, and may remain unchanged for ages in its statute-book, constantly operating upon the people, but without any fresh exertion of the governing force; yet, if that force were to cease, if the government were to be upset by a revolution, and no supreme power existed to compel observance of the law, it must cease to be efficacious. Just so is it in regard to the laws which the Creator has laid down for the government of the universe. We may conceive that, as an eminent philosopher has expressed it, the Deity "has, by creating his materials endued with certain fixed qualities and powers, impressed them in their origin with the *spirit* not the *letter* of his law, and made all their subsequent combinations and relations inevitable consequences of this first impression;" but the continued existence of these materials, and the various actions they perform, are but the manifestations of the continuance of the same mode of operation. To suppose, therefore, as some have done, that the properties first impressed on matter would of *themselves* continue its actions, is not only to deny all that revelation teaches us regarding our continued dependence on the Creator, but is inconsistent with the teachings of the soundest philosophy, regarding His government of the material universe,

Perturbations.

579. If we trace the law of universal attraction into its consequences, we shall find that it not only produces the *regular* motions of the planets round the sun, and of the satellites round their primaries, but that it must also occasion *irregularities* resulting from the action of these bodies upon one another. For there is no reason why the Earth should not be attracted by Venus, Mars, Mercury, or Jupiter, as well as by the Sun; and why its motion should not be affected by them, in a degree pro-

portional to their sizes and distances. Nor, again, if the law of universal attraction be true, is there any reason why the satellites should not be attracted by the sun, as well as by their primaries; and their orbits considerably deranged, by the variation of this attraction with their varying distances from him. Such irregularities actually do occur; and they are so numerous as, altogether, to render the real motions of the heavenly bodies considerably different from those which the simple law already laid down might be expected to produce. Newton had himself contemplated this result; and he successfully applied the principle to the explanation of certain considerable variations in the moon's motion, which were known to the astronomers of that time. But the motions of the planets had not then been studied with sufficient accuracy for the minuter variations which *they* exhibited, to be detected. The existence of these, however, he predicted; and the result has afforded the most triumphant confirmation of the truth of his doctrine. For every such disturbance, or *perturbation*, which can be shown to be a necessary result of the theory, *has been* discovered, provided its amount be great enough to be detected by our present means of observation; whilst, on the other hand, "there is not a single perturbation, great or small, which observation has ever detected, that has not been traced up to its origin in the mutual gravitation of the parts of our system, and been minutely accounted for, in its numerical amount and value, by strict calculation on Newton's principles."

580. Here, then, we see the full perfection of this noble science. Its theory not only accounts for all observed phenomena, but predicts those which, either through insufficient attention, or imperfect means of observation, had previously escaped detection. No other science can approach it in this respect; for although, in many, principles of great generality — that is, accounting for a large number of phenomena—have been discovered, there is none in which there are not a great number of phenomena yet to be accounted for, or in which the action of the principles is unaffected by some unknown causes, often rendering predictions fallacious. In this respect, then, as in many others,

does the study of astronomy conduct us peculiarly near to the Creator; enabling us to conceive, however imperfectly, of His mode of governing the universe; and giving to the dark and finite mind of man some portion of that foreknowledge which is fully possessed only by Him, to whom past, present, and future, are the same, and "a thousand years but as one day."

581. We shall find, in the next chapter, that the masses of the planets are altogether but very small, when compared with that of the Sun. The largest of them, Jupiter, is only 1-1300th part of his bulk; and therefore, supposing the distances of the Sun and Jupiter from the earth to be the same, the latter's attraction for the earth would be no more than 1-1300th of that of the former. But, whilst the mean distance of the sun from the earth is 95 millions of miles, Jupiter, being at a distance of 490 millions of miles from the sun, can never be nearer to us than 395 millions, and may be as distant as 585 millions,—that is, must be always from about 4½ to 6½ times as distant from the earth as the sun is. Hence, supposing their masses equal, his attraction would be weaker in the proportion to the squares of 4½ and 6½ to the square of 1; or as 20¼ or 42¼ to 1. If we suppose Jupiter to be at his nearest point to the earth, therefore, his attraction will be 20 times less than that of a mass equal to himself, situated in the place of the Sun; and as the Sun is 1300 times the bulk of Jupiter, the attraction of the latter must be less by (1300 × 20) 26,000 times, than that of the Sun. As Mars, however, is nearer to Jupiter, and more distant from the Sun, the attraction of Jupiter will produce much more considerable perturbations in his movement; and these become, in fact, very sensible, when his course is accurately watched. The influence of Jupiter upon the four Asteroids is still greater; but his power of attraction is most remarkably shown by Comets, which, when they cross his path at no great distance from him, have their times and orbits greatly altered, or even altogether changed.

582. The most important class of perturbations, however, is that of the motions of the satellites, in consequence of the Sun's attraction; and this has been, of course, most completely studied in the case of our own Moon. Here the attraction of the Sun

for the satellite or secondary becomes subordinate to that of the primary, round which it revolves, in consequence of the near proximity of the latter. For although it may be absolutely greater (as it is in the case of our moon) the greater part of it is expended in keeping the satellite, as well as the primary, in revolution round itself; and it is, therefore, only the *difference* of the Sun's attraction for the primary and secondary, which results from the constant variations in the distance of the satellite, that acts as a disturbing force in altering its course. The average amount of this force, as it acts upon the Moon, was calculated by Newton to amount to no more than 1-638,000th of the force of gravity at the earth's surface, or 1-179th of the principal force which retains the moon in her orbit. In some instances, these perturbing causes operate but for a short time; and tend to produce a contrary effect within a short time afterwards, so as to neutralize the first. But in other instances, the irregularity goes on accumulating, and may produce permanent effects of great consequence. Sometimes these effects increase up to a certain point, and then diminish; and continue to increase and diminish alternately, each set of changes requiring many years or ages for its performance, so that the mean or average condition is not affected. Any series of such changes, requiring a certain length of time for their performance, and repeated again in the next similar interval, are termed *secular* * variations. Of this kind is the variation in the plane of earth's orbit, or the ecliptic, which is produced by the influence of the other planets, to the amount of about 48 seconds every year, and which is recognised by an alteration in the latitudes of the stars. The effect of this change, at present, is to occasion a diminution in the angle between the ecliptic and the equator; but it can never proceed to a greater amount than about $1\frac{1}{3}$ deg.; after attaining this, it will begin to take place in the opposite direction; and a constant vibration within this limit will occur, in periods of enormous duration.

583. Not only do the planetary bodies attract one another, however, but they also attract the Sun himself, which is very far

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* From the Latin *sæculum*, an age, or long period of time.

from being the fixed body he is ordinarily supposed. Their masses are so small, however, in comparison with his, that, even were they all brought into one line, they would not be able to draw his centre more than his own diameter from the point it should occupy. And as, so far from ever being in or near that line, they are to be found, at any period of time, scattered on different sides of the sun, their several attractions for him, in a great degree, balance one another. Still, however, the sun is not fixed; for he performs a revolution around the centre of gravity of the whole system; and this is, in fact, the real centre round which the planets revolve. For if a large and a small cannon-ball be connected by a chain or bar, and be fired from a gun, they will be pretty sure to receive a movement of rotation as well as one of projection (§. 230); and we then observe that neither, strictly speaking, revolves round the other, but that they both revolve round their common centre of gravity. Now, the centre of gravity of a system containing any number of bodies, whose weights and positions are known, is easily ascertained; but as the positions of the planets are constantly changing, the situation of the centre of gravity must also be in continual alteration; and thus the movement of the sun is one which can hardly be described. He is drawn farthest away from his central position, when Jupiter and Saturn are on the same side of him; since their attraction for him is far greater than that of all the other planets put together. But notwithstanding such variations, the place of the sun remains so far unchanged, that the common focus of the ellipses of the planetary orbits is always within his globe;—that is to say, his centre never moves so far from this point, as to cause it to be outside his surface; and after a series of any length, the position of the sun would always be the same as it was, when the planets last had the same places.

584. There are some perturbations, however, which do not seem to be thus kept in check; but which appear, on a cursory examination, to go on increasing without limit, and thus to threaten the overthrow of our system. It is said that Newton himself entertained this fear; and that he supposed that the

stability of the system could not be preserved without a direct interference on the part of the Deity. He did not attempt to solve the question, however; but left it for the mathematicians of the next generation to investigate. It is not a question of observation alone; for observation would lead us to believe in the progressive continuance of many of the changes in question. Thus, the Moon has been revolving more and more quickly round the earth, from the time of the first recorded eclipses; and is now in advance, by about four times her own breadth, of what her place would have been, if it had not been affected by this acceleration. The eccentricity of the Earth's orbit, again, and the obliquity of the ecliptic, have been continually diminishing since the first observations that serve to determine their amount. We might not unfairly suppose, therefore, that such changes would continue to proceed, as they can be shown to have done for thousands of years past; and that the overthrow of the system must be the final result. But the question cannot be so decided. It requires a laborious and profound investigation, which embraces problems of the highest mathematical difficulty. Nevertheless, these difficulties have been overcome; and the wonderful result has been obtained,—that the arrangements of the solar system are stable, all the changes which occur in it being restrained within moderate limits, and having a tendency to balance each other, and to keep each other in check. The orbit of every planet and satellite may be regarded as having an average form, on each side of which it will undergo deviations; but these deviations are never great, and their direction is changed before any serious derangement is produced. The periods required for a single series of these changes are in many instances of thousands of years in length, and in some cases even of millions; and hence it is that these apparent derangements have been going on in the same direction since the beginning of the history of the world. But the restoration is, in the sequel, as complete as the derangement; and in the meantime, the disturbance never attains an amount sufficient to make a serious alteration in the adaptations of the system.—With this wonderful demonstration, the names of Lagrange and Laplace (both

French mathematicians)—especially of the latter—will ever remain connected; as that of Newton is with the doctrine of universal attraction.

585. The stability of the system has been shown by Laplace to depend upon the fact, that the planets all move in the same direction, in orbits of small eccentricity, and slightly inclined to each other. This being the case, whatever be the masses of the planets, all their *secular* variations are periodical and included within very narrow limits; and they have thus a kind of vibration on the two sides of an average state, to which they will constantly tend to return. Now it is very interesting to remark in this connexion, that the planets Mercury and Mars, which have much the largest eccentricities among the old planets, are those in which the masses are much the smallest. The mass of Jupiter is more than 2000 times that of either of these planets; and if his orbit were as eccentric as that of Mercury, all the security for the stability of the system which Laplace has pointed out, would disappear. The earth and smaller planets might in that case change their nearly circular orbits into very long ellipses, and thus might fall into the sun, or fly off into remote space. It is further remarkable that in the newly discovered planets, of which the orbits are still more eccentric than that of Mercury, the masses are still smaller, so that the same provision holds good here also. There is no necessary connexion between the principle of universal attraction, and the uniformity in the direction of the revolution of the planets round the sun; nor has any reason been shown by the mathematician, why the smallest masses should have the greatest eccentricities,—a fact which is still more remarkable in regard to comets. The uniform direction of the revolution, however, is fully accounted for by the theory which regards the whole solar system as having originated in a mass of nebulous matter gradually undergoing condensation into solid spheres,—a theory which has the merit of accounting for numerous phenomena not otherwise to be explained, and of giving what is at least a probable solution of the great problem of the history of the universe (Chap. XXII). And it is probable that the connexion between the small size of

the revolving body, and the eccentricity of its orbit, may be shown to be but a result of the same principle.

Universality of the Law of Gravitation.

586. Hitherto we have considered the operation of the grand principle of mutual attraction upon the bodies composing the solar system alone; and the question now presents itself,—whether this principle is restricted to our own system, or extends throughout the universe. From what we know of the uniformity and simplicity of the Creator's operations, we might reasonably suppose that the same power, which binds together the parts of one system, should be employed to produce a corresponding effect in another. But however probable such an idea might seem, it could not be regarded as a law of nature, unless confirmed by the observation of facts. Such confirmation has been derived from a most remarkable and unexpected source. The vast distance of even the nearest of the fixed stars, prevents them, in spite of the enormous size which we may attribute to them, from exercising any perceptible attractive force on the bodies composing the solar system; for though the existence of such an attraction has been *suspected* in regard to certain comets, whose orbits seem to extend to an almost incalculable distance from the sun, it has never been *proved*. Again, although we are almost unquestionably entitled to regard each of the fixed stars as holding the same rank with our sun, and therefore to suppose, without improbability, that every one of those luminaries has its own system of planets and satellites in revolution around it; we must remember that this is only a speculation, and that it affords no real confirmation to the doctrine of universal attraction.

587. But the observations of astronomers have recently shown that, in many instances, these suns revolve around each other, or rather around their common centre of gravity, in systems of two, three, or even more (§. 526-532); and that their revolutions are evidently governed by the same laws as those which govern the movements of the bodies composing the solar system;—a magnificent generalization, which leads us to regard our own comparatively insignificant group, vast as it

appears to us, as presenting, within its own narrow space, an example, in a form adapted to our comprehension, of the mode in which the Creator is operating, in "worlds beyond worlds, and system beyond system," through that vast universe, whose extent impresses us with the highest conception of *infinity* of which our finite minds are capable.

588. Well has it been said by the illustrious philosopher, to whom we owe the confirmation and extension of this idea, which was first suggested by his no less illustrious father, that "there is something in the contemplation of general laws, which powerfully persuades us to merge individual feeling, and to commit ourselves unreservedly to their disposal; while the observation of the calm, energetic regularity of Nature, the immense scale of her operations, and the certainty with which her ends are attained, tends, irresistibly, to tranquillize and re-assure the mind, and render it less accessible to repining, selfish, and turbulent emotions. And this it does, not by debasing our nature into weak compliances and abject submission to circumstances, but by filling us, as from an inward spring, with a sense of nobleness and power which enables us to rise superior to them; by showing us our strength and innate dignity, and by calling upon us for the exercise of those powers and faculties, by which we are susceptible of the comprehension of so much greatness, and which form, as it were, a link between ourselves and the best and noblest benefactors of our species, with whom we hold communion in thoughts, and participate in discoveries, which have raised them above their fellow-mortals, and brought them nearer to their Creator." *

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* Sir J. Herschel's Discourses on the Study of Natural Philosophy, p. 16.

CHAPTER XVIII.

GENERAL ACCOUNT OF THE SUN, PLANETS, AND THEIR SATELLITES.

589. Having now considered the general laws regulating the movements of the bodies composing the Solar system, and the manner in which those movements are seen by the inhabitants of the earth, we are prepared to inquire in more detail, into the actual forms, dimensions, distances, rates of movement, and physical peculiarities of these bodies individually: and the Sun, as by far the largest, as well as the centre of the whole system, naturally claims our attention first.

The Sun.

590. The Sun is not only many times larger than any one of the bodies which revolve around him, but exceeds by many thousand times the united bulk of them all. By the ancients, he was very naturally supposed to be a great globe of fire; but this opinion has been greatly modified by the discoveries and speculations of modern science. His stupendous bulk may be judged of from his apparent size, when his distance is known to us. There is not much difference between the apparent diameters of the Sun and Moon; but whilst the latter is at a distance of only 237,000 miles from the Earth, the latter is 95 millions of miles off, and in order to appear of the same size must have more than 400 times the real dimensions. The actual diameter of the Sun is about 882,000 miles; it is therefore about 111½ times that of the Earth; and, as the bulks of spheres are to each other as the cubes of their diameters, the whole mass of the Sun is to that of the Earth as 1,384,472 to 1. The weights of the

two globes, however, (supposing it were possible to compare them) do not bear the same proportion; for the density of the Sun is much less than that of the Earth,—that is, any given bulk of his substance would weigh much less than the same bulk of the Earth's substance. It would be, in fact, very little more than one-fourth; so that, as the Earth weighs about $5\frac{2}{3}$ times as much as an equal mass of water (§. 101), the Sun would not weigh half as much more than his own bulk of that liquid. His weight is calculated to surpass that of the Earth, by 354,936 times; and his attraction for bodies on his surface will be proportionably great.

591. When the Sun is viewed with a telescope, through the medium of a darkened glass, which prevents the glare of light and the concentrated heat from being injurious to the eyes, his surface is seen to exhibit large opaque spots, which slowly change their places and forms. Many of them retain their forms, however, long enough to be recognised as the same after a considerable interval; and by these it has been ascertained, that the Sun revolves on his axis in 25 days. A part of the apparent change in form which these spots present, is due to the altered directions in which we view them. Thus, a spot which has a circular form, when we see it in the middle of the Sun's disc, and consequently look directly at it, will gradually become narrower and narrower, as it is made to approach the edge by the Sun's rotation, in consequence of our seeing it more and more in an oblique direction; until, at last, it disappears altogether. But the actual size and form of the spots is continually changing; old ones are gradually becoming smaller, as if they were cavities in process of being filled up; whilst new ones are making their appearance. Sometimes a single spot breaks into two or more. Their size is frequently enormous; so that they have been seen without the assistance of a telescope. There is a record of one whose diameter was a twentieth part of that of the Sun, or nearly 45,000 miles. The whole duration of such appearances is seldom more than six weeks; hence we must suppose the walls of such a space as that just mentioned to approach at the rate of 1000 miles a day. Even the part of the Sun's disk which is not occupied by spots,

is finely mottled with an appearance of minute dark points; and these also are found to be continually changing their state. In the neighbourhood of the large spots, again, the surface is often observed to be traversed by luminous streaks, curved and branching, amongst which spots frequently break out.

592. Several explanations respecting the nature of these spots have been proposed at different times. For a long period they were regarded as heaps of ashes or cinders, the refuse of the burnt fuel which had sustained the mighty solar conflagration. The continual changes in their appearance, however, and the great rapidity of these changes, seem to indicate that they are occasioned by the movements of fluid rather than of solid matter, and of matter in a gaseous state, rather than in a liquid form. There appears, therefore, considerable probability in the supposition, that the luminosity of the sun is due, not to the intense heat of his entire mass, but to a luminous atmosphere enveloping his globe, and occasionally permitting its surface to be discerned through gaps or rents occasioned by fluctuations in this medium. This luminous atmosphere is supposed by Sir W. Herschel, to rest upon another more like our own; on the top of which floats a layer of clouds. These clouds will reflect to us a considerable portion of the light of the luminous atmosphere above them; and by this reflection they will produce the *penumbra*, or shaded border, which the spots generally present. The luminous atmosphere appears to be in a state of constant commotion; and the causes which produce this disturbance probably originate in changes in the solid globe itself. When accumulated into waves, it will constitute the bright spots and ridges; and it is remarkable that one of these ridges always surrounds a spot, as if the luminous atmosphere were heaped up there, in consequence of some explosive force below which has made a rent or passage through it. Of the nature of this luminous atmosphere, we can at present only speculate; but it may be imagined to be, in a partially condensed form, that from which all matter originated, and which, until condensed into the liquid or solid state, retains its self-luminous properties.

Mercury.

593. Mercury is the smallest of all the primary planets, as well as the nearest to the sun; and from these two circumstances, we know less of his constitution than we do in regard to most of the others. Owing to his orbit being far within that of the earth, we never see him at any considerable distance from the sun (§. 550); so that he is almost always lost in the superior brilliancy of that luminary. When at the period of his greatest elongation eastwards, he is an evening star, which is distinguishable a short time after sunset, as a small but very brilliant disc. In the course of a few weeks, however, it changes its place so as to remain constantly near the sun; and in a short time afterwards it attains its greatest elongation westwards, so as to rise before the sun in the morning, when it is visible for a short time, until lost in the brightness of the opening day. Little more can be discovered with the telescope respecting the appearance of Mercury, than that is round, and exhibits phases during its revolution round the sun. It is very seldom that any spots can be discerned on its surface; and these are not permanent, like those of the moon, but rather resemble those of the sun, or the belts of Jupiter, in their changeable character. From observation of these, and of a peculiar projection which is seen at one end of the crescent when the planet is horned, it has been concluded that Mercury rotates around his axis in about $24^h\ 5^m$. This axis appears considerably inclined to the plane of the orbit; so that there is probably a still greater variety of seasons in Mercury, than in our earth.

594. The mean distance of Mercury from the sun is a little more than 37 million miles; but his orbit is more elliptical (or oval) than that of most of the other planets; and its eccentricity (or the distance between the centre and the focus of the ellipse, §. 565) amounts to as much as one-fifth of the mean distance. Through this orbit he moves in somewhat less than 88 days, with a velocity of 110,000 miles an hour. This extraordinary rate of motion is necessary, to prevent the planet from being drawn towards the sun, into which he would fall, by the power-

ful attraction of that enormous mass, which (in consequence of the diminished distance) is far stronger than that which acts upon the earth. The transit of Mercury, or his passage across the sun's disc, when he is in conjunction with the earth, has been already noticed (§. 561); the appearance then presented by him, which is that of a minute black spot, sufficiently proves that he shines entirely by the light reflected from the central luminary. That light has been calculated to be seven times more intense than the proportion which we receive; and the heat which Mercury derives from the sun must exceed, in a corresponding degree, that which the earth obtains from the same source. Hence, if Mercury be peopled with living beings, its inhabitants must be very differently constituted from those of our globe. The *density* of Mercury is about $2\frac{3}{4}$ that of the earth; or about $15\frac{1}{2}$ times that of water (§. 101); hence his weight is greater than that of a globe of quicksilver, of the same size. But as his diameter is only about 3136 miles, and his bulk only 6-100ths that of the earth, the quantity of matter he contains is little more than one-sixth that of our globe.

Venus.

595. Venus is the most beautiful of all the planets; and it was doubtless from this circumstance that she received from the ancients the name of the Goddess of Beauty. Her diameter is much greater than that of Mercury, being about 7800 miles, or nearly that of the earth; and as she receives a considerable proportion of light from the sun, she is seen by us as not only a large but a brilliant star. Her apparent size differs considerably, according to the part of her orbit in which she is. It is remarkable, however, that although her disc is so large, when seen through the telescope, it cannot be made out so definitely as that of the more distant planets. The intense lustre of its illuminated part dazzles the sight, and exaggerates every imperfection of the telescope. Like Mercury, it exhibits no permanent spots, and rarely any even of a transient nature; hence it may be surmised (from the probable nature of the belts and spots of Jupiter and Saturn, §. 616), that we do not see the real surface of these planets, but an atmosphere loaded with clouds, capable of reflect-

ing a large portion of the light that falls upon it, and serving perhaps to mitigate the otherwise intense glare of their sunshine, changing it into a bright diffused light, resembling that produced by a ground glass globe over the flame of a solar lamp. Certain irregularities can be seen, however, upon her edge, which show that mountains exist upon her surface; and by the return of these, her period of rotation on her axis is known to be 23½ hours.

596. The distance of Venus from the sun is about 70 millions of miles; and her revolution is performed in about 224⅔ days. Her orbit is inclined about 3½ degrees to the ecliptic, and it is very nearly circular. As the whole of her orbit is within that of the earth, she is never seen by us on the side of the heavens opposite to that of the sun; but she is not restricted to a range of distance from him so narrow as that of Mercury. She is called a morning or evening star, according as she rises before the sun, or sets after him. Some days after she has passed between the earth and the sun, (at which time her illuminated side is turned entirely away from us,) she is seen in the morning at a little distance from him on the west. Her light is then faint; and her form at that time is easily made out with a telescope to be that of a crescent, the concave edge of which is turned towards the sun. She continues to move westwards, increasing her distance from the sun, and at the same time becoming brighter and brighter, in consequence of presenting to us more and more of her illuminated face. At last she arrives at her point of greatest elongation, where she seems to remain stationary for a time; by which period, her crescent has enlarged to a semicircle. She then commences to move towards the east; and her motion is gradually accelerated, until she comes into the same line with the sun. During this time, we see more and more of her illuminated face, but her brightness diminishes, as she approaches the sun; and when she comes into conjunction with him, we lose sight of her altogether in the blaze of his light, even if she be a little above or below him, and be not hidden behind him. She then continues her motion towards the east, and becomes visible for a short time after sunset; her disc is then quite round, but apparently very small, in consequence of

her increased distance in this part of her orbit. As she continues her course eastward, she increases her distance from the sun, and is consequently seen for a longer time after his setting; at the same time she becomes larger and more brilliant; but her disc is gradually narrowed, so that, at the time of her greatest elongation, her form is again that of a semicircle. Lastly, as she enters upon that part of her orbit which passes between the earth and the sun, she again takes a westerly direction, and approaches him, until she comes into conjunction with him; during this period, her illuminated face is being withdrawn from us, and the semicircle is gradually narrowed to a crescent, which diminishes until we lose it altogether. When Venus crosses the sun's disc, she can be distinctly seen with the naked eye, as a well-defined dark spot. These transits are very rare; and they are of the highest importance to astronomers, as affording the best means of measuring the distance of the sun from the earth; on which measurement the calculation of all the other distances is based (§. 513).

597. Although almost as large as the earth, Venus moves with greater rapidity, in order to compensate for the more powerful attraction of the sun. Her rate of movement is about 80,000 miles per hour, or 23 miles per second;—a velocity of which we can scarcely form a distinct idea. The axis round which Venus revolves, is inclined 75 degrees towards her orbit, so that the poles are, in fact, but little elevated above it. As these poles are always directed towards the same part of the heavens, they are alternately pointed towards the sun, and turned away from him (§. 661). Owing to the very great inclination of the axis, the sun will be shining directly, during one part of the annual revolution, upon a circle only 15 degrees from the north pole; and in the opposite part of the orbit, upon a circle only 15 degrees from the south pole. These circles will correspond to our tropics; and when the sun is shining upon them, the equatorial regions will receive so little of his rays, that a winter almost as severe as that of our arctic zone will reign there. The sun crosses the equator twice in every annual revolution; and at each time it will bring with it the hottest summer. Hence, as there

is winter at the Equator, whether the sun is shining on the northern or the southern pole, all the portion of the globe that is moderately distant from it, will experience the greatest heat of a vertical sun, as well as the almost complete withdrawal of that source of light and warmth, twice in every annual revolution of the planet; whilst not only at the poles themselves (as in the earth), but within a circle of considerable extent around them, will the sun continue above the horizon, or on the other hand, remain completely invisible, during alternate periods, each occupying half her revolution in her orbit.

598. Numerous attempts have been made to ascertain whether Mercury and Venus are attended by satellites; but none have been discovered, nor is it probable that they possess any.

Tellus.

599. It seems desirable to introduce here, for the sake of comparison with the other planets, the chief particulars of the Earth's physical condition, its diurnal and annual movements, and its relations to other members of the solar system. We may form an idea of the appearance which the earth would probably exhibit, when seen from the distance of 40 or 50 millions of miles, from that which Venus presents to us when at the time of her greatest brilliancy. The light of Tellus to Venus will be fainter than that which Venus reflects upon us; but, on the other hand, the disc of our planet is larger, and will be seen at the full when the two are at their nearest point, on the same side of the sun. At this period, their distance will not be more than about 25 millions of miles,—the mean distance of the earth from the sun being 95, and that of Venus 70 millions. When, however, the two planets are on opposite sides of the sun, their distance will be increased to 165 millions of miles; hence the apparent size of Tellus, as seen from Venus, will be more than 6½ times as great in the second case as in the first. It is when she is on the other side of the sun, that the illuminated side of Venus is most fully turned towards us; and it is, therefore, when she is approaching that state, but before her light is rendered faint by being overpowered by that of the sun, that her beauty is the

greatest. On the other hand, as the orbit of Tellus is entirely beyond that of Venus, a part at least of the illuminated disc of the former will be turned towards the inhabitants of the latter, in every portion of its orbit; and the whole disc will be so at both the periods just mentioned. At the former epoch, as Venus is then between the earth and the sun, Tellus will be seen as a large and brilliant star, almost resembling a small moon, rising just as the sun sets, and giving light during the whole night. At the latter period, however, her light will be lost to the inhabitants of Venus, as that of Venus is to us, in consesequence of her being then seen in the same direction with the sun.

600. The difference of the polar and equatorial diameters of the earth is quite sufficient to cause her disc to appear flattened at the poles, though by no means in the same degree with Jupiter. The polar diameter, according to the latest calculations, is 7900 miles; and the equatorial 7926 miles; the difference, therefore, 26 miles, is about 1-300th part of the whole diameter. The inequalities upon the earth's surface must be considerable enough to give an irregular edge to its disc, like that which Venus presents to us; and from these its rotation round its axis might be determined. This rotation is really completed in 23 h. 56 min.; the additional four minutes being required, as already explained, to bring any point to the same position in regard to the sun. The axis of rotation is inclined about 23½ degrees to the ecliptic or plane of the orbit; and from this results that variety in the seasons, to which the constitution of the living inhabitants that people the various parts of this globe, is so beautifully adapted. The annual revolution of Tellus round the sun is completed in 365¼ days; and her rate of movement is about 68,000 miles per hour. The eccentricity of her orbit is about 16 parts in 1000; but this makes a difference in her greatest and least distance from the sun, of nearly three million miles. The density of the earth is about 5⅔ that of water; so that its whole mass would weigh about the same with a globe of arsenic (the lightest of the ordinary metals) of equal bulk.

601. The planet Tellus is attended by one satellite, the

Moon. Her large apparent size is entirely due to her proximity to us; for she is smaller than any of the heavenly bodies we have yet considered. Her real diameter is about 2160 miles; and her bulk only about 1-49th that of the earth. Her density is so much less, that her actual weight is probably no more than 1-77th that of the earth. The mean distance of the moon from the earth is about 237,000 miles; which distance, vast as it is, is but little more than one-fourth of the diameter of the sun's body; so that, supposing the sun to occupy the place of the earth, his surface would be twice as far from his centre, as the orbit of the moon is distant from the centre of the earth. The orbit of the moon is much more elliptical than that of the earth, the eccentricity amounting to 5½ parts in 100; so that she is 26,000 miles nearer to him at one time than at another,—a difference which produces the contrast between a *total* and an *annular* eclipse (§. 677). The orbit of the Moon is inclined somewhat more than five degrees to that of the earth; and from this inclination it happens, that the sun is not eclipsed by the passage of the Moon between his disc and the earth, at every conjunction; and that the Moon is not eclipsed by passing into the earth's shadow at every opposition. During her revolutions round the earth, one of which is completed every 29½ days, she exhibits to us a series of *phases*, produced by the varying degree, in which the side of her globe that is illuminated by the sun, is turned towards us. Very nearly the same part of her globe is always presented to the earth; but each part is successively turned towards the sun during one of her revolutions. This is in consequence of her turning once round upon her own axis, during each of her monthly revolutions round the earth (§. 674). The same thing is true of all the satellites of Jupiter; and probably of those of Saturn and Uranus also.

602. This will occasion a very curious effect, as to the appearance of the primary to the inhabitants (if there be any) of its satellites. Thus the Earth will be seen, by the residents in our Moon, as a luminary of enormous size, immoveably fixed in the sky, presenting a different aspect in each part of its diurnal rotation, and exhibiting a series of monthly phases correspond-

ing with those which the moon presents to us, but occurring at different times. Thus, when the Moon is at full to us, the dark side of the earth is presented to her; whilst, at our new moon, her inhabitants will see the whole illuminated face of the earth; and, when she passes between the sun and the earth, in such a manner as to produce a solar eclipse, her inhabitants will see her shadow traversing the earth's disc. From one entire half of the moon, the earth will never be visible. Our disc will probably appear covered with variable spots, resulting from the cloudiness of our atmosphere; and these will be arranged, in the equatorial regions, into zones or belts, by the action of the trade-winds.

603. In consequence of the mutual attraction of the earth and moon, they would fall towards each other, if each were influenced by no other force. The proportional rate at which each would move, and the point at which they would meet, is determined by the proportion between their masses. Their attraction for one another will be proportional to their respective weights (§. 89); that is, as the weight of the earth is 77 times that of the moon, the attraction of the Earth for the moon will be 77 times that of the Moon for the earth. Consequently the moon will move 77 times as fast as the earth; and if the whole space were divided into 78 parts, the Moon would move through 77 of these parts, whilst the Earth moves through only one; and the spot where they would meet (provided the whole mass of each could be compressed into one point) which is their common centre of gravity (§. 119), is at a distance of 1-78th the whole length, from the centre of the earth, and therefore actually beneath its present surface.

Mars.

604. This planet is the first of those, which, as their orbits include that of the earth, are termed the superior planets. It is at once distinguished by its dark red hue; and it was from the resemblance of this to blood, that the ancients gave the name of the God of War to this planet. When seen through a telescope, Mars exhibits a rounded disc; and as this does not present any well-marked indentations or projections, it is probable that there

are no lofty mountains upon his surface. But very distinct and constant peculiarities of hue are seen in different parts of his disc; and the outlines of these are so strong, that they may be well supposed to be the boundaries of continents and seas. The accompanying figure represents the appearance of Mars, as seen through Sir J. Herschel's 20-feet reflecting telescope. The supposed continents are distinguished by reflecting the red and fiery hue which characterizes the light of this planet; and this is supposed by Sir J. Herschel to be owing to a reddish tinge in the soil, which may resemble that of the ochreous and red sandstone districts on the surface of our own planet. Contrasted with this (according to the law of complementary colours, which will be explained in the volume on Optics), the supposed seas appear greenish. The red hue of Mars is commonly explained by supposing that he is surrounded by a dense and extensive atmosphere, which may produce the same effect on his light, as a winter's fog gives to the light of our morning sun; but for the existence of such an atmosphere, there are, in the opinion of Sir J. Herschel, no sufficient or even plausible arguments. It has been remarked that these peculiar appearances on the surface of Mars are not always seen with equal distinctness; although, when well seen, they have always precisely the same aspect. Hence it may be surmised, that the planet is not entirely destitute of atmosphere and clouds; and this idea is strengthened by the appearance of brilliant white spots at the poles, which have been supposed, with much probability, to be snow, since they disappear when they have been long exposed to the sun, and are most strongly marked when they have just emerged from the long night of a polar winter.

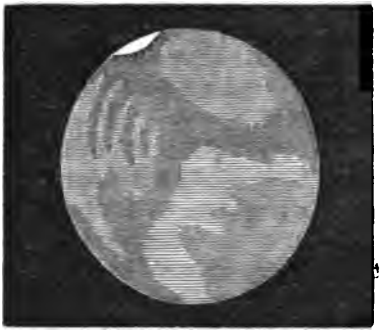

FIG. 163.—TELESCOPIC APPEARANCE OF MARS.

605. The apparent diameter of Mars varies, of course, with his distance from us; which is more than four times as great when he is in opposition, as when he is in conjunction. His real diameter is about 4100 miles, or rather more than half that of the earth; and his volume will therefore be about 1-7th. His density is rather less than that of the earth; and the actual weight of his globe will therefore be somewhat less than 1-8th that of ours. By continued observation of the spots upon his disc, it has been found that Mars turns upon an axis inclined about 32 degrees to the plane of his orbit; and that this diurnal rotation is accomplished in about 24½ hours. From the inclined position of his axis, there will be greater variety of seasons on the surface of Mars, than on that of our own globe. The polar winters will be longer and more severe; whilst the summers will be hotter,—the poles being then turned more directly towards the sun. In consequence of his increased distance from the Sun, however, the whole proportion of light and heat received by him from that source is much less than that which we enjoy; that of Mars being only 43-100ths of ours. The orbit of Mars is very elliptical; his mean distance from the sun is 146 millions of miles; but his excentricity amounts to nearly one-tenth of this. Consequently there is a great variation in the rapidity of his motion, in different parts of his orbit; and it was from the study of this variation that Kepler was led to the discovery of the important law regulating the motions of the planets in their elliptical orbits. The annual revolution of Mars round the sun occupies nearly 687 days, or nearly double our year. Since his orbit is entirely beyond that of our planet, his place in the heavens is much more variable than that of the two inferior planets, which are never seen at any great distance from the sun; for though he sometimes appears near the sun, he is often quite in the opposite part of the heavens, setting when the sun rises, and rising when he sets. According to his position in his orbit, a larger or smaller proportion of his disc will be seen; but he will never be totally obscured, nor will he present the crescentic appearance which we see in Venus and Mercury. To the inhabitants of Mars, the

earth will present appearances very closely corresponding to those which Venus exhibits to us; our light, however, will be less brilliant, and our disc (in consequence of the great interval between the orbits of the earth and Mars) will be smaller.*

Vesta, Juno, Ceres, and Pallas.

606. Until the commencement of the present century, no planet was known to exist between Mars and Jupiter. The existence of such a planet, however, was suspected by Astronomers; chiefly because the interval is much greater than that which might be anticipated in that part of the solar system, if the same proportion holds good throughout, as exists in the case of the nearer and remoter planets. This proportion (first pointed out by the late Professor Bode of Berlin) is a very simple one; it is, that the *interval* between each orbit † and the next goes on doubling, as we pass from the centre to the circumference of the system. Thus the interval between the orbits of Mercury and Venus is about half of that between the orbits of Venus and the Earth; this interval, again is about half of that between the orbits of the Earth and Mars. Now the space between the orbit of Mars and that of Jupiter greatly exceeds this proportion; so greatly, in fact, that if we were to suppose the existence of a planet, between whose orbit and that of Mars there should be an interval equal to twice that between the orbits of Mars and the Earth, an interval would remain between *its* orbit and that of Jupiter in which the same proportion would be followed; and this proportion would then extend itself regularly to the orbits of Saturn and Uranus. No reason for this proportion can be given from theory; and it is not as strictly accurate as the laws discovered by Kepler: but there was enough probability in the idea, to fix the attention of Astronomers; and they were rewarded by discovering, not one only, but *four* planets, moving in orbits which correspond pretty closely with the expected situation; the small size of which had been the cause of their having previously escaped notice.

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* No Satellite has yet been seen to attend this planet.

† By this is meant, not the distance of the planet, but the *space* or area between the orbits.

607. When these four small planets, commonly known as the *Asteroids*, were first discovered, it was conjectured that they were the fragments of some greater planet, which formerly revolved in the orbit where it was expected, and which was blown to pieces by some internal explosive force, or shattered by collision with a comet. "This," says Sir J. Herschel, "may serve as a specimen of the dreams in which astronomers, like other speculators, occasionally and harmlessly indulge." If we speculate at all on the subject, we shall probably find a much better explanation, in the general theory of the formation of the solar system, which will be given in the last chapter. Their minute size has prevented many circumstances of their condition from being ascertained. They agree, however, in these;—that their mean distances from the Sun, and their period of revolution around him, are not very dissimilar; and that, although the *forms* of their orbits are very different, so that they cross each other, there is one point through which they all pass.

608. *Vesta* is the nearest to the sun, and has the shortest period. She was, however, the last discovered, having remained unknown till 1807, when she was first seen and recognised as a planet, by a pupil of Olbers of Bremen—the discoverer of Pallas. Of her dimensions, nothing can be certainly stated; for, when observed by Herschel, with a telescope of great magnifying power, she did not present the appearance of a disc, but only that of a brilliant point. Consequently we know nothing as to her rotation on an axis, nor the inclination of that axis. Her mean distance from the sun is about 225 millions of miles. Her orbit seems to have about the same degree of excentricity as that of Mars; but it appears to be very irregular, probably in consequence of the perturbations produced by the attracting influence of the larger planets upon her small mass. Her orbit is inclined to the ecliptic rather more than 7 degrees; and her period of revolution round the sun is 1325¾ days, or about 3⅔ years. In regard to her distance from the Sun, and her period of revolution, she departs more from the general average than does either of the three other asteroids.

609. *Juno* was discovered by Harding of Lilienthal in 1803.

Her diameter has been estimated at 1320 miles; but the truth of this estimate is very uncertain. Her mean distance from the sun is about 256 millions of miles; but the excentricity of her orbit is enormous, amounting to more than one-fourth of her mean distance; consequently her orbit is very elliptical, and her distance from the sun is far greater at some times than at others. Her orbit is also remarkable for its great inclination to that of the earth's; the angle between them being 13 degrees, or nearly twice as great as that of the orbit of Mercury. Her period of revolution round the sun is 1592½ days, or about 4⅓ years.

610. *Ceres* was the first discovered of the asteroids; having been observed, by Piazzi of Naples, in 1801. Her appearance is that of a nebulous star, surrounded by variable mists; which induced Herschel to suppose this planet possessed of an atmosphere. This, together with her small size, produces a great uncertainty respecting her real diameter; which has been estimated by Schroeter at 1320 miles, and by Herschel at no more than 140. Her mean distance from the sun is about 264 millions of miles; and the excentricity of her orbit is rather less than that of Vesta. Its inclination to the ecliptic is about 10½ degrees. Her period of revolution is 1681⅓ days, or about 4⅔ years.

611. *Pallas*, like Ceres, presents a very indistinct appearance, when viewed with a very powerful instrument; and her real diameter is equally uncertain. By Schroeter it has been stated at 1950 miles; whilst Herschel estimated it at no more than 140. The mean distance of Pallas from the sun is about 267 millions of miles; but her orbit is extremely elliptical, its excentricity being nearly the same with that of Juno. Its inclination to the ecliptic is far greater than that of any other planet; being 30½ degrees. Her period of revolution is 1686½ days, or about 4⅔ years.

612. It is remarkable that, of two out of these four asteroids, the orbits should be so extremely elliptical; whilst those of the other two are but moderately so. Each of the elliptical orbits crosses all the rest. There is in many other respects a correspondence between Vesta and Ceres on the one hand, and Juno and Pallas on the other.

Jupiter.

613. Jupiter is by far the largest of the planets; and, next to Venus, is the most brilliant. It is owing to his great distance from us and from the sun, that his appearance is not more striking. Were he at the distance of Venus, his apparent diameter would be 12 times as great as hers; and (since the surfaces or areas of circles are as the squares of their diameters) the quantity of light that his disc would reflect to us from the sun would be 144 times that which we receive from Venus. His real diameter is estimated at something less than 87,000 miles; but there is a considerable difference between the polar and equatorial diameters, which is even discoverable by the eye (when assisted by the telescope) without any instrument of measurement. This results from a flattening of the poles, to the extent of about 1-15th of the whole diameter; so that his form bears a strong resemblance to that of an orange. Here, then, we observe the influence of centrifugal force, carried to a much greater extent than we can trace in the form of the Earth; and we should consequently expect to find that the rotation of the planet upon his axis is much more rapid. This is actually the case; for the whole of his immense mass turns round once in a little less than ten hours. The axis round which he turns is nearly perpendicular to the plane of his orbit; consequently the sun always shines nearly upon his equator; and there can be but little variation in the seasons, nor in the length of the days and nights in different parts of his globe, and at different periods of his year. Moreover, the proportion of light and heat which he receives from the sun, is only about 1-27th part of that which comes to us. Hence we must believe that, if this planet is peopled with animated beings, their conformation must be very different from that of the inhabitants of this globe.

614. The bulk of this planet is about 1300 times that of our earth; but his weight (supposing we could compare them in a balance) would not be found nearly as great. For it has been ascertained that his *density* is only about a quarter that of the Earth, being nearly the same with that of the Sun; hence if the

average density of the earth be estimated at 5⅔ that of water (§. 101), the density of Jupiter will be less than 1½, or about the same as that of *coal*, which is one of the lightest of minerals. If he could be weighed against the earth, therefore, he would be found to be not more than 325 times as heavy, notwithstanding the enormous disproportion of his bulk.

615. The revolution of Jupiter round the sun occupies 4332½ of *our* days, or nearly 12 years; consequently during a whole revolution of the earth, Jupiter has only moved through one-twelfth part of his orbit; thus changing his place in regard to the sun to the same degree only that the earth does in a month. Now as Jupiter's rotation on his axis is accomplished in less than 10 hours, the number of days and nights which his inhabitants will witness during one of his years will be (4332½ × 24÷10) about 10,398. His mean distance from the sun is about 493 millions of miles. The excentricity of his orbit is about 48 parts in 1000, or three times that of the earth; and its inclination to the ecliptic is very small, being only 1° 18′ 52″.

616. When Jupiter is examined with a good telescope, his surface is seen to be crossed by a number of zones or bands, of a browner hue than the rest of his disc; these are commonly termed his belts. They are by no means uniform in their appearance; sometimes there is only one seen; sometimes as many as eight; and they have been occasionally, but rarely, seen to be broken up and distributed over the whole surface of the planet. Branches running out from them, and dark spots, are by no means uncommon; and it is from the attentive observation of these, that the period of his rotation on his axis has been determined. The belts are always parallel to

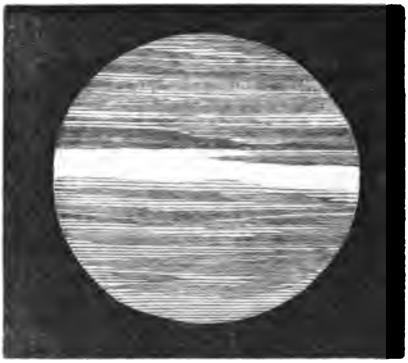


Fig. 164.—Telescopic Appearance of Jupiter.

the equator; that is, they correspond exactly with the direction of the movement of the surface; and from this fact, when taken in connexion with the continual changes which they are undergoing (new appearances being sometimes witnessed in an hour or two), it has been supposed, with considerable probability, that they are produced by changes in the atmosphere of the planet, determined by currents that resemble our trade-winds. These currents must be very much stronger than they are with us; for each point on the equator of Jupiter has to move, during the rotation of that planet, through a circle 11 times greater than that through which any point on the earth's equator revolves; and as the whole circle is completed in 5-12ths of the time, the actual velocity of movement is about 26 times as great. The brownish bands and spots are regarded as the body of the planet, and the luminous portions as clouds.

617. Jupiter is attended by four moons or satellites, which are large and brilliant enough to be seen with a telescope of very moderate power. The discovery of these was, in fact, one of the first results of the invention of the telescope, at the commencement of the 17th century; and the existence of this miniature system was employed by Galileo as a strong argument against the absurd notions, which were upheld by the authority of the church, as well as by the prejudices of men, respecting the motion of the sun round the earth. So bigoted were those whom he attempted to convince, that many of them even refused to look through his telescopes, affirming that the system which they were to reveal was an optical deception, or an invention of the devil! Such are the absurdities to which some men will commit themselves, rather than give up a cherished prejudice.

618. The satellites of Jupiter are known, according to their distances from him, as the 1st, 2nd, 3rd, and 4th. They move in orbits which are nearly circular, and which are almost in the same plane with that of the planet; consequently, as this is but little inclined to that of the earth, we see their orbits edgeways; and instead of a circular movement, they present to us only a kind of vibration in straight lines, from one side of the

planet to the other. This would be easily made intelligible by a very simple experiment. Suppose that a lamp were placed at some distance from us, and that a candle were made to move around it in a horizontal circle; if we were not near enough to distinguish when the candle is nearer us, and when more distant, we should only see it apparently moving from one side of the lamp to the other. If four candles were made to move, in the same manner, through circles of different sizes, we should see corresponding appearances presented by all of them; and that which revolves in the largest circle would seem to move the furthest from the planet. When the moons pass in front of the planet, they can be distinctly seen upon his disc, on which they throw shadows that look like small ink-spots. And when they pass behind him, they are themselves eclipsed in his shadow. As this shadow is thrown by the sun, and the line in which it is seen from the earth may be very different, the satellite may enter the shadow of Jupiter, long before it appears to us to approach its disc.

619. These eclipses of Jupiter's satellites happen very frequently; for neither of the first three can ever escape passing into the shadow of the planet, each time that it traverses the part of its orbit most distant from the sun, on account of the great size of Jupiter, and the small inclination of their orbits. The fourth, having a more inclined orbit, and being at a greater distance, escapes being eclipsed during about a third part of Jupiter's year. Moreover, the times of the revolution of the satellites are very brief. The first makes its whole circuit in about $1^d\ 18\frac{1}{2}^h$; the second in $3^d\ 13\frac{1}{4}^h$; the third in $7^d\ 3\frac{3}{4}^h$; and the fourth in $16^d\ 16\frac{1}{2}^h$. The size of the first, second, and fourth, are nearly the same with that of our moon; the first being rather smaller, and the others larger. The third is the largest, being a little larger than Mercury. By observation of their discs with a telescope of the greatest power, Herschel found that each satellite rotates on its own axis in precisely the same time that it occupies in revolving round its primary; so that the same face is always turned towards Jupiter. Hence, there is a remarkable conformity in the nature of their movement,

with that of our Moon; and the same result will happen,—that, whilst they constantly present the same face to Jupiter, all sides are presented successively to the Sun (§. 674).

620. Again, supposing these satellites to be the residence of living beings, the planet Jupiter would be seen by the inhabitants of those sides which are turned towards it, as an enormous but faintly illuminated moon, going through the same phases or changes of appearance, which our moon exhibits to us, and which *we* present to *her* inhabitants. The distance of the first satellite from Jupiter is rather greater than that of the moon from the earth. Supposing it to be the same, the apparent size of Jupiter to an inhabitant of that satellite, would be as much greater than the apparent size of the moon to an inhabitant of the earth, as Jupiter's diameter exceeds that of the moon. This is in the proportion of about 40 to 1; and the whole surface of Jupiter (being as the square of the diameter) would be about 1600 times that of the moon as she appears to us. The quantity of light reflected by it would not, however, be proportionally great; since any portion of Jupiter's surface, equal in size to that of the moon, will only receive and reflect 1-25th part of the same solar light; consequently the whole quantity reflected will be (1600÷25) 64 times that which the moon affords to us.

621. From the frequency of the eclipses of the satellites of Jupiter, and the length of time they last (being about 2¼, 2¾, 3½, and 4¼ hours, for the four satellites respectively) it may be expected that they are not often to be all four seen at once. It is not uncommon for only two to be visible for a short time together; occasionally only one is seen; and there is an observation on record (probably the only one of the kind) that on the 2nd of November, 1681, Jupiter was seen without any satellites. There is a curious relation between the movements of the first three satellites; from which it happens that, when we know the situations of either of the two, we can fix that of the third; and also that they cannot all be eclipsed together,—since, when either two are on one side of the planet, the third will be on the opposite.

622. It was by the observation of the eclipses of Jupiter's

satellites, that the fact was first discovered (by Roemer, a Danish astronomer, in 1675) that light does not travel instantaneously, but has a certain definite velocity. This was ascertained by comparing together a series of observations upon the eclipses, which had been collected during successive years; for it was then found that the eclipses which took place, when the Earth was between Jupiter and the Sun (and consequently at the nearest possible point to Jupiter), were observed about 8 minutes sooner than the time when they might be expected by calculating the average of the observations; and that, on the other hand, the eclipses that took place when the Earth and Jupiter were on opposite sides of the Sun, were observed about 8 minutes later than the usual time. Hence it was inferred by Roemer, that the light of Jupiter requires 16 minutes to pass from the nearest to the farthest point in the earth's orbit; and as the distance of these two points is about 190 millions of miles, he estimated the velocity of the transmission of light at about 11¾ millions of miles per minute, or at about 192,000 miles per second.

623. This idea, startling as it seems at first, has been completely confirmed by the discovery of Bradley, respecting the aberration of light in the case of the Fixed Stars. By the term *aberration of light*, we understand a certain variation in the apparent places of the heavenly bodies, which is the combined result of the annual movement of the earth, and of the *progressive* (not immediate) transmission of light. This variation was discovered by Bradley, when he was attempting to ascertain the parallax of the fixed stars.—If a person stands still in a shower of rain, of which the drops are descending vertically, they will fall upon the top of his head; but if he run forwards, they will strike his face, in the same manner as if he were still, and they were driven towards him by the wind. Hence if he were carried forwards in such a manner as not to be conscious of his own motion, the striking of the drops upon his face would lead him to suppose, that the rain, whilst descending, was being brought by the wind from a point in advance of him, so that it does not come from the part

of the sky just above his head (as it would seem to do, if he were at rest), but from that towards which he is looking.—This illustration will account for the aberration of light, better than a longer explanation. The rays of light proceeding from any star, do not reach the earth in an instant, but require a very appreciable time to travel thither (§. 515); and during the whole of this period, the earth is moving onwards in its annual revolution. If the earth remained at rest, all the heavenly bodies would appear in their true positions, since their rays would strike it in the direction in which they left it. But as the earth moves onwards, the rays will fall on the face (as it were) of the observer; and he will consequently see each star a little in advance of its true place. If the direction and rate of our movement were always the same, we should always see the same difference between the apparent and real places of the stars; and we should thus be ignorant of its existence. But as we do in fact revolve in an orbit which is nearly circular, the stars appear to move in very small orbits, whose forms correspond with the perspective representation of our orbit to them. Those which are directly above the plane of our ecliptic, and which would see the earth (could they discern it) moving in a circular path, appear to describe very small circles. Those stars, on the other hand, which are on or near the plane of the ecliptic,—from which, therefore, our orbit would be seen edgeways, and the earth vibrating backwards and forwards along it,—perform a similar backward and forward movement. And those which have an intermediate position, so that the earth's orbit would be seen from them as a long narrow ellipse, perform similar long narrow ellipses. It is necessary, of course, to make allowance for this aberration, in all accurate observations on the position of the stars.

Saturn.

624. Though the planet Saturn has not the pre-eminence among the rest, which Jupiter possesses on account of his enormous size, it is distinguished by a beautiful appendage, which is quite unique,—namely, the *ring;* this is not visible, however,

to the naked eye. Although not much inferior to Jupiter in size (his diameter being about 79,000 miles), his greater distance from us makes his apparent dimensions much less, whilst his distance from the Sun reduces the proportion of light which he receives and reflects; consequently to the naked eye Saturn presents the aspect of a nebulous star of a dull leaden hue; and as his motion is very slow, he may be easily mistaken for a fixed star. With a telescope of very ordinary power, however, his extraordinary ring may be seen; but the exact appearance of this, and its separation into two or more, can only be well seen by a telescope of first-rate character.

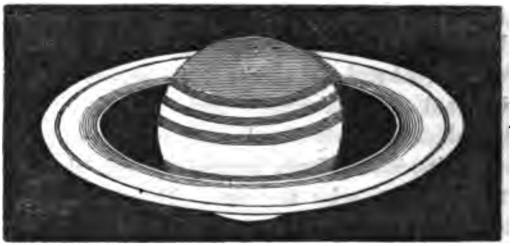


FIG. 165.—TELESCOPIC APPEARANCE OF SATURN.

625. The diameter of Saturn, being nearly 10 times that of the earth, his bulk is about 995 times greater; but his density is most remarkably low, being but a little more than an eighth of that of the earth, or about the same as that of light wood. Like Jupiter, he turns rapidly on his axis; his day being about 10h. 29m.; and his poles are flattened in nearly the same proportion. The axis of rotation is considerably inclined, however, to the plane of its orbit; so that there must be in Saturn the same kind of variety of seasons as in our globe. But as the light and heat received by Saturn from the central luminary, are not above 1-90th part as strong as that which we derive from it, the character of these seasons, and consequently of the living inhabitants (if there be any) of the planet, must be quite different from any of which we can form an idea. Indeed the constitu-

tion of the planet itself must be very unlike that of our earth. No water could exist on its surface; since, being heavier than the planet itself, every solid would float upon it. But there is probably *some* fluid; since the disc of the planet is crossed by the same belts as those which traverse the face of Jupiter; and if, as is probable, these belts are due to the existence of clouds, there must be a liquid, by the conversion of which into vapour, these clouds are produced.

626. The distance of Saturn from the sun is about 915 millions of miles; and the time of his revolution is proportionally long, being 10,759 days, or rather less than 29½ years. The excentricity of his orbit is rather more than that of Jupiter, being about 56 parts in 1000; and the inclination is also rather greater, being still, however, but 2½ degrees.

627. The *ring* of Saturn is a circular plane, completely surrounding the equator of the planet, but nowhere touching it. From the variation of our position in regard to that of Saturn, and from the circumstance that the axis of Saturn (like that of the earth) is always parallel to itself, we obtain many different views of this extraordinary appendage. Sometimes we see it exactly edgewise, in which case it is said to disappear, being invisible to all but the best telescopes, on account of its extreme thinness. It then appears merely as a thin bright line, crossing the disk of the planet, and projecting on each side. More commonly, however, we see it as an oval of greater or less breadth, according to the direction in which we view it. We could never see the whole circle at once, unless we were to look down upon it from a point beyond one of its poles. That the ring is a solid opaque substance, is shown by its throwing a distinct shadow upon the body of the planet; and from its exhibiting, on the side remote from the sun, a corresponding shadow thrown upon it by the planet. When viewed with a telescope of sufficient power, the surface of the ring is seen to exhibit several black lines; but one of these, near the outer margin, is conspicuous, and seems to divide the ring into two, the separation of which was first noticed by Dr. Herschel. The following are

the dimensions of the rings and of the body of Saturn, as calculated by Sir J. Herschel from Prof. Struve's measurements:

	MILES.
External diameter of outside ring	176418
Internal ditto	155272
Breadth of external ring, therefore	10573
External diameter of inside ring . . .	151690
Internal ditto	117339
Breadth of internal ring, therefore . . .	17175
Space between inner and outer rings	1791
Equatorial diameter of the planet	79160
Space between the planet and inner ring . .	19090
Thickness of the rings not exceeding . .	100

628. By means of certain spots upon the ring, Dr. Herschel was enabled to ascertain, that it rotates about an axis which corresponds to that of Saturn, in 10h. 19m. 161sec.; or in a period somewhat less than 10 minutes shorter than that of the planet itself. It has been calculated that this period is exactly that which a satellite would possess, if made to revolve in an orbit corresponding with the middle of the breadth of the ring. The centre of rotation of these rings is not perfectly fixed, but itself describes a small orbit. That it should do so was shown, by the celebrated mathematician Laplace, to be essential to the stability of the system, before the fact was ascertained by observation. This necessity may easily be understood, by referring to the laws formerly explained in regard to the rotation of bodies round an axis. (Chap, VII.) It is obvious that, if the ring be perfectly circular, and of equal density in every part, and if the body of the planet be a perfect spheroid, (that is, if every point on its equator, and on the circles parallel to it, be equally distant from the axis,) and the centre of the rings correspond exactly with its own, the attraction of the planet would never disturb the rings, since it would draw all parts of them equally towards its centre. But if any other force were to produce the slightest change,—so that one portion of the ring were made to approach the planet, and another portion were moved to a greater distance from it,—the attraction of the planet would operate with increased force

upon the part thus brought nearer, and less strongly upon the farther portion; and thus the displacement would continually increase, until, at last, the inner edge of the ring would be drawn into contact with the planet itself. To produce this disturbance, the attraction of the satellites alone would have been sufficient. Now it was shown by Laplace, that this instability would be prevented, by giving to the centres of the rings a slight motion round that of the planet; and recent observations have shown that such a motion actually exists. Sir J. Herschel compares this constant struggle between the preserving and destructive powers, to the mode in which a practised hand will sustain a long pole, resting on the finger, in a perpendicular direction, by a continual and most imperceptible variation of the point of support. Both these forces are extremely feeble; but they so antagonize one another, as to prevent the stability of the system from ever being so far disturbed that a catastrophe would result. It is beautiful to observe how these powers are thus balanced against each other; the disturbance that would arise from the direct attraction of the satellites for the ring, being prevented by a trifling peculiarity in the motion of the ring, which is itself but the result of another operation of the same force of universal attraction.

629. "The rings of Saturn," it is remarked by Sir J. Herschel, "must present a magnificent spectacle from those regions of the planet which lie above their enlightened sides, as vast arches spanning the sky from horizon to horizon, and holding an invariable situation among the stars. On the other hand, in the regions beneath the dark side, a solar eclipse of fifteen years in duration, under their shadow, must afford (to our ideas) an inhospitable asylum to animated beings, ill compensated by the faint light of the satellites. But we shall do wrong to judge of the fitness or unfitness of their condition from what we see around us; when, perhaps, the very combinations which convey to our minds only images of horror, may be, in reality, theatres of the most striking and glorious displays of beneficent contrivance."

630. Saturn is accompanied by no fewer than seven satellites, of which the most distant is nearly as large as Mars.

With the exception of this last, the orbits of the satellites are so nearly in the same plane with the equator of the planet, and therefore with the ring, that they seem (like those of Jupiter) merely to move from side to side of his disc. Indeed, the two inner ones, which just skirt the edge of the ring, and move exactly in its plane, had escaped observation until Sir W. Herschel directed his largest telescope towards them; and he then saw them like minute beads strung upon the very thin thread of light, to which the ring was at that time reduced. The three next also require powerful telescopes to see them; but the last but one, which was the earliest discovered (by Huyghens, in 1755), is tolerably conspicuous. The periods of revolution of these satellites vary from about 22½ hours, which is that of the first, to 79⅓ days, which is that of the largest and most distant. The law discovered by Kepler, respecting the proportion between the distances of the planets from the Sun, and the times of their revolution, holds good equally, on a miniature scale, in regard to the satellites of Saturn.

Uranus.

631. This planet is the most distant of those at present known to constitute the solar system. It is too minute to be visible to the naked eye; and consequently altogether escaped observation before the discovery of the telescope. There is reason to believe that it was frequently noticed by astronomers, but that it was mistaken for a fixed star. Its variable position was first attentively watched by Dr. Herschel, who recognised it as a planet in the year 1781. His own name was at first proposed for it; but he was himself desirous that it should receive the appellation of Georgium Sidus, in honour of the King, who had greatly aided him in his astronomical researches. It is now generally agreed, however, that as all the other planets have received names from the Greek and Roman deities, this ought not to be an exception; and the title *Uranus* seems very appropriate, being the continuation of the order in which the more distant of the principal planets have been named. For, in the heathen mythology, Jupiter was the father of Mars, and

Saturn the father of Jupiter; hence, a planet more distant still should receive the name of the father of Saturn.

632. The distance of Uranus from the Sun is about 1840 millions of miles, or more than twice that of Saturn; and he receives no more than 1-362nd part of the light and heat which we enjoy. Through this vast orbit, he revolves in a period of about 30,787 days, or 84 years; and consequently has not performed more than three-fourths of a revolution, since his planetary nature was first discovered. His immense distance from us prevents us from becoming fully acquainted with the details of his state. Thus his appearance, when viewed through the most powerful telescopes, is only that of a small round disc, uniformly but faintly illuminated, of a bluish white colour, and presenting neither rings, belts, nor discernible spots. Hence, the question of his rotation on an axis cannot be determined; but there can be little doubt, from the analogy of all the other planets, that he does so revolve, though the time is entirely uncertain. His diameter is about 35,000 miles, or between 4 and 5 times that of the Earth; and his bulk is consequently about 80 times as great. His density seems to be somewhat less than that of Jupiter, so that his actual weight would be about 17½ times greater than that of the earth.

633. This planet was stated by its discoverer to be attended by six satellites; of these, however, only two have been clearly proved to exist. Of these, which would be the 2nd and 4th, if all six are present, the times of revolution are about 8¾ days, and 13½ days, respectively. They present a most remarkable peculiarity, which was first noticed by Sir W. Herschel, and which has been since confirmed by his son;—that whilst the orbit of Uranus himself is but very little inclined to the ecliptic, their orbits are nearly perpendicular to it, being inclined almost 79°;—and that in these orbits their motions are retrograde, their revolution round their primary being from east to west, instead of from west to east, as is the case with every other planet and satellite. It is generally found that the direction of the orbits of satellites, is nearly the same with that of the equator of the primary; and it will be shown hereafter (Chap. XXII.) that there is probably

a connexion between their revolution round it, and its own rotation on its axis. If this be the case, the axis of Uranus must be almost parallel with the ecliptic, so that his poles will almost be in its plane. The effect of such an arrangement upon his seasons (provided that his axis, like that of the Earth, always retains its parallelism to itself, §. 661) would be most extraordinary. As at the poles of our earth, the days and nights last half a year, in consequence of the moderate inclination of its axis to the ecliptic, so in Uranus not only the poles, but a very large proportion of his globe, will be alternately exposed to the sun and removed from it, during the half of *his* year of 30,687 days.

634. How different must be the constitution of any living beings that are adapted for such a residence, from that of which we can form any idea! and yet how limited would be our conception of the Creator's power, if we were to imagine, even for a moment, that there is any impossibility, or even an improbability, in the existence of such beings? It may be that they are destined to a life so long, that the days and nights of 42 years' length are to them but as the 24 hours' change between rest and activity, to the human race. The nations that inhabit our torrid zone can scarcely conceive of the nature of cold; nor could they suppose that either man, beast, or plant, could exist, in situations where the genial rays of the sun are received but for a few weeks in every year. And yet experience proves their error; for even where the sun is completely hid during four months out of every twelve, can man enjoy life, and wonder that any should desire a different climate. In like manner, the inhabitant of the frigid zone does not readily give credit to the accounts he hears of the perpetual summer that reigns within the tropics; and wonders how any human beings can live where there is no blubber or seal's flesh! Narrow and restricted as such notions appear to us, they are not less the result of experience, than those which we form respecting the condition of other worlds; and whilst we laugh at the ignorance of the Hindoo or Esquimaux, we should be careful lest we fall into the same error. Of course we have no means of even guessing the conformation of

living beings that are to inhabit what would be to us the intolerable and destructive heat of Mercury, or the dreary cold and darkness of Uranus; and it would be useless, therefore, to speculate on the subject. These are, perhaps, among the subjects on which our knowledge will be extended, in that state in which the intellect of man will be continually undergoing elevation towards the perfection of his Maker,—where all darkness shall be enlightened, all difficulties and obstructions shall be removed, and where, in learning more and more of the wonderful works of the Creator, we shall receive higher and yet higher motives to humble adoration of His infinite perfections.

635. The following illustration, proposed by Sir J. Herschel, is well adapted to convey to the mind an idea of the relative magnitudes and distances of the parts of our system. "Choose any well-levelled field or bowling-green. On it place a globe two feet in diameter; this will represent the sun; Mercury will be represented by a grain of mustard-seed, on the circumference of a circle 164 feet in diameter for its orbit; Venus a pea, on a circle 284 feet in diameter; the earth also a pea, on a circle of 430 feet; Mars a rather large pin's head, on a circle of 654 feet; Juno, Ceres, Vesta, and Pallas, grains of sand, in orbits of from 1000 to 1200 feet; Jupiter a moderate-sized orange, in a circle nearly half a mile across; Saturn a small orange, on a circle of four-fifths of a mile; and Uranus a full-sized cherry, or small plum, upon the circumference of a circle more than a mile and a half in diameter. To imitate the motions of the planets in these orbits, Mercury must pass through a space equal to its own diameter in 41 seconds; Venus in $4^m\ 14^s$; the earth, in 7^m; Mars, in $4^m\ 48^s$; Jupiter in $2^h\ 56^m$; Saturn in $3^h\ 13^m$; and Uranus, in $2^h\ 16^m$." It may be added, that such motions would actually take place, if the representatives of the planetary masses were set in motion by the required impulse (§. 171); provided that they were influenced by no other force than the attraction of the central globe, or representative of the Sun, and could move freely through space, without friction or resistance of the air. It may assist us in comparing this miniature representation with the reality, if we remember that the pigmy globe of two feet in

diameter must be expanded into a sphere of nearly 900,000 miles in diameter, or to 2,348½ *million* times its size. What, then, must be the orbit of Uranus? And yet the whole of this vast system is but a point in the universe, no larger in the estimation of the inhabitants (if such there be) of the nearest of the fixed stars, than the smallest of the satellites of Saturn or Uranus appears to us.

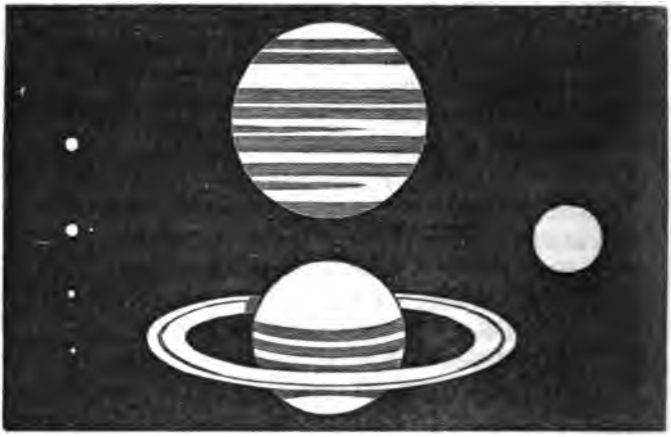


FIG. 166.—COMPARATIVE SIZES OF THE PLANETS. At the top, *Jupiter*; below, *Saturn*; on the right, *Uranus*; on the left, *Venus*, the *Earth* and *Moon*, *Mars*, and *Mercury*.

CHAPTER XIX.

OF COMETS.

636. We have seen that the name by which these bodies are known, was originally given to them on account of the peculiar luminous train or tail by which they are usually accompanied (§. 458); and for a long period this train was believed always to form a part of a cometary body. At the present time, however, astronomers are acquainted with comets which are destitute of tails; and can no longer, therefore, consider these as their distinctive characters. They regard as Comets those heavenly bodies of a luminous and nebulous appearance, which approach towards, and recede from, the Sun, after the manner of a planet in a single revolution. Some of these are known to revolve round the sun in regular elliptical orbits; and their appearance at particular times may be predicted with almost the same certainty as that of the planets. Others, again, seem to move in a curve which does not return into itself, and consequently do not reappear; as if, whilst moving in empty space, by a force which had previously impressed them, they had come within the sphere of the Sun's attraction, had been made for a time to revolve around him, and had again been launched into space, in a path that would carry them, perhaps, to the verge of some other system, to be attracted by *its* sun, and thus to perform a temporary revolution around it.

637. It was shown by Newton that one mass may move round another by the attraction of the latter, combined with its own proper force of motion, not only in an ellipse, but in either of the other two *conic sections*, the *parabola* and the *hyperbola*,—more generally, however, in the former of these two than in the

latter. Now the difference between the vertex of a parabola, and one of the ends of a very elongated ellipse, is so trifling, that it is very difficult to distinguish them; and as Comets only become visible to us, when they are going through this part of their curve, it is scarcely possible to calculate with certainty the nature or dimensions of their orbits, or the period of their return. The only instances in which this calculation can be accurately made, are those of comets having but moderately elliptical orbits, resembling those of the more excentric planets, such as Juno and Pallas (§. 609); for in these the form of the curve described by the comet, as it approaches the sun and becomes visible, is sufficiently unlike the parabola, to be readily distinguished from it.

638. The first attempt to predict the return of a comet, and thus to include this class of bodies within the control of the laws governing the system in general, was made by Dr. Halley, the contemporary of Newton. A remarkable comet having appeared in the year 1682, Dr. Halley calculated the elements of its orbit, —or in other words, laid down its path, from the observations of Flamsteed and others. The same methods of calculation applied to the observations of Kepler in 1607, upon a comet having a similar appearance, gave results,—in regard to the inclination of its orbit, the place of its nodes, the situation of its perihelion, and the *retrograde* direction of its movement,—so closely conformable to these, that little doubt could be entertained in regard to the bodies being the same. Between these two periods, there was an interval of 75 years; and reckoning backwards from 1607 to the same amount, Dr. H. searched in astronomical records for an account of a similar comet in 1531 or 1532. Such a one he found to have been observed; and by applying the same method of calculation to the recorded observations of its progress through the constellations, he deduced results almost precisely identical. Going still further back, he found that a similar comet had appeared in 1456; but its elements he could not determine, from the want of sufficient observations. This comet had a tail which spread over 60° of the heavens, and excited great consternation in Europe; its appearance being regarded

as connected with the most serious event in that age,—the menacing success of the Mahomedan armies. A remarkable comet is recorded as having been observed also in 1305,—or two periods of 75 years previously,—and also in 1230; and the correspondence of the times is so striking, that it may be reasonably supposed to have been the same; and it is not difficult to account for the absence of any notice of its appearance in 1380 or 1381, since no regular astronomical records were kept at that period.

639. Having shown the identity of the comet of 1682 with that of 1607 and of 1531,—to say nothing of the earlier appearances,—Halley seemed fully justified in predicting that the comet would re-appear in 1758 or the beginning of 1759,—its period being about 75½ years. He left the precise time in some degree of uncertainty, having perceived that the interval had not been exactly the same in previous instances, and being disposed to think that the attracting influence of the planets might occasion a considerable disturbance in its course. His prediction was given confidently, and with a full sense of its importance; he desired that it should be remembered that its author was an Englishman. Several astronomers took up the subject; but it was not until 1757,—a year before the expected return of the comet,—that any one ventured to grapple with the very difficult question of the perturbations produced by the planets. It was then taken up by Clairaut, a French mathematician, who found that the return of the comet would be retarded to the amount of 518 days by the action of Jupiter, and 100 days by that of Saturn; so that it should pass its perihelion by the middle of April, 1759. He gave notice, however, at the same time, that, having been hurried in his calculations, he had neglected small quantities, which in 76 years might amount to about 30 days *more or less.* The predictions of Halley and Clairaut were fully justified by the event; for the comet re-appeared at the end of 1758, and passed its perihelion on the 12th of March, 1759, or just within the limit assigned by Clairaut. Its brightness, however, was much less than on former occasions, partly in consequence of the different position of the earth; and it does not seem to have been readily visible to the naked eye.

640. Numerous and accurate observations were made of its progress in the heavens; but no complete calculations were made as to its orbit, and the perturbations of the planets, until near the time of its expected re-appearance in 1835. The computation was again undertaken by two French mathematicians; and they fixed the period of its perhelion passage for the month of November, 1835; the one predicting it for the 4th, and the other for the 7th,—the difference being due to a different estimate of the quantity of matter in the perturbing planets. The actual passage took place, however, on the 15th of November, the comet having been first seen on the 5th of August, and remaining visible to the naked eye through the ensuing winter. This error of 8 days only, in a period of 76 years, cannot be regarded as surprising, when it is considered for how short a portion of its orbit the comet is visible; and how much a very small error in determining the form of one of its extremities will affect the estimate of its length;—when it is remembered, also, how much it suffers from the perturbing influence of the planets, and how difficult it must be—with our very imperfect knowledge of the structure of the comet and the quantity of matter it contains—to estimate this aright. In fact, this degree of accuracy must be regarded as a wonderful proof of the completeness of our knowledge of the laws, that govern the movements of bodies even so erratic as these. During the whole time of its appearance in 1835, its movements were very attentively watched by various able observers, both British and continental; and a body of observations has been collected, which will probably afford, to any calculator who shall undertake to compute from them the time of its re-appearance in 1911, the means of doing so with still greater accuracy. It is not probable, however, that this will be accomplished until the time approaches; since the fame to be acquired by this laborious investigation, and its correspondence with the actual result, is the only reward which it is likely to receive; and most men would prefer acquiring it whilst living, to leaving it to add fresh lustre to their memories after their death.

641. This comet, whose periodicity was the first discovered, long remained the only one whose character in this respect was

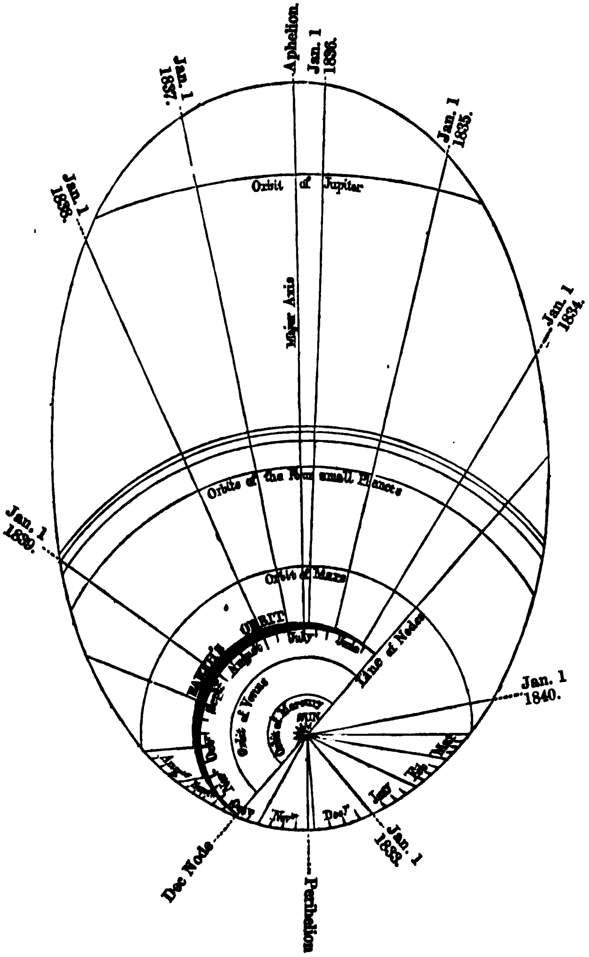
known. In 1818, however, a small comet was discovered, the elements of whose orbit so closely corresponded with those of a comet which had been seen in 1805, that there could be little doubt of their being the same. From these elements M. Encke calculated its period, and found that its orbit is elliptical, and that it only required about 1200 days, or $3\frac{3}{10}$ years, to travel through its whole path; so that between 1805 and 1808 it must have re-appeared three times without having been noticed. This might easily be imagined; since the comet is very small and its light very weak, so that it is imperceptible to the naked eye. Still, as the heavens are now being continually and attentively surveyed by a large number of astronomers, the total absence of any record of it is remarkable. On examining older records, however, it was found that the appearance of a comet, whose orbit corresponded closely with that of 1818, had been recorded in 1786 and in 1795; and that these dates corresponded with those in which this body might be calculated to have performed its revolution. Although, therefore, the period was found to be so much shorter than might have been expected, M. Encke's determination of it was fully justified by past observations; and his prediction of its re-appearance in June, 1822, was completely borne out by the result.

642. Since that time it has regularly made its appearance, very nearly at the places and in the times predicted by calculation. But there is a regular diminution of its period of revolution, and a gradual approach of its orbit towards the sun, for which mathematicians and astronomers do not feel able to account, otherwise than by supposing that all space is filled with a resisting medium, so thin or *rare* in its character, that it has not offered the least perceptible impediment to the earth or planets in their movement round the sun, but quite enough to operate sensibly upon a little "whiff of vapour," such as this comet is believed to be. It might be supposed that the effect of such a resisting medium would be to retard its movement, and thus to *increase*, instead of diminishing, the time of its revolution; but by referring to the explanation of the nature of curvilinear motion formerly given (§. 172), it will be seen that the effect

of such resistance will be to diminish the force with which the body is moving onwards, and thus to allow the central attraction to draw it nearer, by which the revolution will be rendered more rapid, and its period consequently shortened. The ultimate result must be, that the comet will be drawn into the sun, unless it be first dissipated altogether;—a result which will be presently shown (§. 652) to be by no means impossible. The nature of this resisting medium will be hereafter considered (Chap. XXII.).

643. The only other comet at present known to have a regular period, was observed in 1826 by M. Biela, an officer then residing at Prague. On a calculation of the elements of its orbit, and a comparison of these with the results of similar observations on preceding comets, they were found to correspond with those of a comet which had appeared in 1805 and also in 1772; and the periodical return of this body seemed therefore probable. On this supposition, its orbit must be regarded as an ellipse, and not as a parabola; and when its path was thus laid down from the ascertained elements, it was found that its revolution would take place in 2460 days, or about 6¾ years, and that its re-appearance might be expected, therefore, in 1832. In order to ascertain the precise period of its return, it was of course necessary to study the perturbing influence of the planets; and when their places were ascertained, and compared with its course, the curious result was obtained, that it would cross the orbit of the Earth, only about a month before the arrival of the latter at the point of intersection. This announcement excited much curiosity, and amongst timid persons a good deal of excitement, amounting even to alarm. It was quite destitute of foundation, however; and might have been completely removed by tracing the history of this comet a little further back; for in 1805 it must have passed within 5 millions of miles from the earth, whilst in 1832, it was never within 60 millions. The comet did actually appear in September, 1832, according to prediction, and in the part of the heavens where it was expected. It is a small insignificant comet, looking like a collection of nebulous matter, and not having either a tail, or any appearance

of a solid nucleus. It appeared again in the latter part of 1838; and will again present itself in 1845. The accompanying



REPRESENTATION OF THE ORBIT OF THE COMET OF 1832, WITH THE RELATIVE POSITION OF THE ORBIT OF THE EARTH.

diagram represents the orbit of this comet, compared with that of the earth; and marks the point where they intersect, which happens to be very near the descending node. The time at which the comet reached its perihelion in 1832 is seen to be in the middle of November; it crossed the earth's orbit on the 29th of October; but the earth did not reach the same point until the 30th of November. When the revolutions of this comet shall have been observed with the same frequency and accuracy as those of Encke's comet have been, it will be of great importance to ascertain if it exhibits a similar acceleration in its period of revolution; since, unless it does so, the doctrine of the resisting medium can scarcely be true.

644. Now, in contrast with these facts, which show the regularity with which some Comets perform their revolutions, others may be mentioned, which show that, by the operation of the very same causes, their movements may be rendered altogether irregular. Yet are they still under the dominion of the same laws; and if we are acquainted with *all* the causes that are in operation, the result may be predicted with equal certainty. One of the most remarkable of these cases is that of a comet which appeared in June, 1770. As soon as a sufficient number of observations had been made upon its movements, astronomers set to work to calculate the elements of its orbit. These were not found to correspond with the elements of any comet previously known; and yet, after very numerous and careful observations, it was satisfactorily determined that its orbit could not be a parabola,—that it must return into itself, forming an ellipse,—and that the comet must, therefore, have a regular periodic revolution round the sun, the time of which would be about 5½ years. It was shown that all the observed positions of the comet corresponded most exactly with an elliptical orbit, whose long diameter was only three times that of the Earth's orbit. Having so rapid a revolution, and being of tolerable size and brightness, it might be supposed that some record of former appearances of this comet could be discovered; but the most careful research did not throw any light upon it, for no such record could be found. And what was for some time a source of

the greatest perplexity to astronomers, and a frequent subject of a variety of small sarcasms amongst those who affect to laugh at star-gazers as unprofitable wasters of time,—this Comet has never since shown itself.

645. But by simply comparing its course with that of the planet Jupiter, the whole mystery was explained. For it was ascertained that in its subsequent revolution, it would approach so near to Jupiter, that his attractive force would be 200 times greater than that of the Sun; and that the form of the orbit of the Comet would be thus so completely changed, that its revolution would require 20 years, and that its least distance from the sun would become 393 millions of miles, so that it would not be visible from the earth. Reasoning *backwards* in the same manner, it was found that, on its approach to the Sun in 1767, it must have encountered Jupiter; but that his influence must have been then exerted in an opposite direction, so as to change a long ellipse—whose shortest distance from the sun was 597 millions of miles, and the period of its revolution which was 50 years—into the smaller orbit, in which it performed two revolutions. Thus the *novelty* of the appearance of this comet in 1770, and its subsequent complete disappearance, are fully accounted for: and the very fact which led some to doubt the universality of the Newtonian principle, has become a striking confirmation of it. In order to meet Jupiter a second time in the part of his orbit where the change was produced, this comet must have crossed its perihelion in 1776; and its having escaped observation is to be accounted for, by its having come to this point during the day.

646. Although these are the only Comets, whose periodical return to the neighbourhood of the Sun has been ascertained with anything like certainty, the number that have at different times been visible from the earth is very much greater; and it is probable that these constitute but a very small proportion of the total number that visit our system. Of this number, varying estimates have been formed; but all agree in regarding it as enormous. The two following will give an idea of the principles upon which they are computed. It is stated by Sir J. Herschel,*

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* Preliminary Discourse, p. 62.

that 140 comets have appeared within the earth's orbit, during the last century, which have not been again seen. If we allow 1000 years as the average period of these, then we might expect to see as many new ones in another century, and so on until we have seen them all *once;* and at this rate about 1400 must have their range within the Earth's orbit. But the orbits of the comets are so extensive, that even the perihelion distance of many whose existence has been ascertained, is beyond the orbit of Mars; and as we have a right to suppose that they are distributed with some degree of uniformity, the number ranging within the boundaries of the orbit of Uranus may be computed from that ranging within the Earth's orbit, by comparing the dimensions of the two. Now, as Uranus is at about twenty times the Earth's distance from the Sun, the amount of space included within a sphere of the diameter of his orbit is (20 × 20 × 20 =) 8000 times that which would be included by a corresponding sphere of the diameter of the Earth's orbit; and multiplying this number by 1400, we obtain 11,200,000 as the whole number of comets, which may be supposed with probability to come within the range of the planetary system.—M. Arago has formed a similar estimate, from the number which are known to have their perihelion distance within the orbit of Mercury; and on this foundation he computes the whole number at about 3½ millions. But he considers that this number may be doubled, in consequence of various causes which may intercept from our view the comets which approach so near to the sun;—so that the total number may be estimated at not less than 7 millions.—There is sufficient agreement between these two estimates, to cause us to regard the probable number of comets occasionally visiting our system as certainly not less than *five millions.*

647. Comets are not, like most of the planets, restricted to a zone of the heavens that does not extend much on either side of the ecliptic; for their paths have every possible inclination to that of the earth; and they may therefore be seen in almost any part of the sky.—Moreover, they differ from the planets remarkably in this,—that the motions of about one-half of them are *retrograde,* that is, from east to west. They are only visible to

us when near their perihelion points; and as they then travel with great rapidity, they can seldom be watched for any long time. Their light is principally, if not entirely, derived from that of the sun; and their brilliancy must increase, therefore, in proportion as they approach him. The celebrated comet of 1680 seems to have had its perihelion point at a shorter distance from the sun, than any on which observations have been made; this being only about 590,000 miles from his centre, or 147,000 miles from his surface. It was calculated to move at the rate of 880,000 miles an hour, when in that part of its orbit; and to have gone from one side of the sun to the other in about 10½ hours. If its enormous centrifugal force had ceased, when it passed the perihelion, it would have fallen into the sun in about 3 minutes. At its nearest approach to the sun, it would have received from him a heat 27,500 times greater than that which comes to us; and it is probable that a heat of such intensity would be sufficient to convert into vapour every terrestrial substance with which we are acquainted. The sun's apparent diameter, at that distance, would be 70 degrees; and to an observer situated in the comet, it would, therefore, extend nearly from the zenith to the horizon. The period of this comet is supposed to be about 575 years; and, if this be the case, its orbit must be so long, that, at its greatest distance from the sun, his apparent diameter would be no more than 14 seconds, which is not half as great as the apparent diameter of Mars when nearest to us. At that distance, his heat could not have been perceptible; and the comet must therefore have been exposed to the temperature of the space that intervenes between our different systems, which is estimated at 580 below the zero or 0° of Fahrenheit's thermometer.

648. Comets are usually described as consisting of a *head* and a *tail*. The head is a large but ill-defined nebulous spot, which is usually much brighter towards the centre, where there is a very brilliant spot, often resembling the body of a planet, or a star,—termed the *nucleus*. The tail (where it exists, for it is not universally present) consists of a stream of light proceeding from the head, and *always directed towards the side most remote*

from the sun; it is often slightly curved, however; bending towards the region which the comet has left. It commonly seems formed by the union of two distinct streams, which close together a little behind the head; sometimes these remain distinct along their whole course; and occasionally they branch out into five or six divisions, as was the case with that of the comet of 1744. The tail has generally very much the appearance of the luminous trains left by some bright meteors, or of the fiery track of the sky-rocket—only that it has no sparks or perceptible motion. This magnificent appendage has sometimes an immense apparent as well as real length. The comet of 1618 is stated to have been attended by a train no less than 104° in length; so that if the body had been upon the southern point of the horizon, and the tail had shot up vertically into the sky, it would have passed through the zenith, and nearly reached the

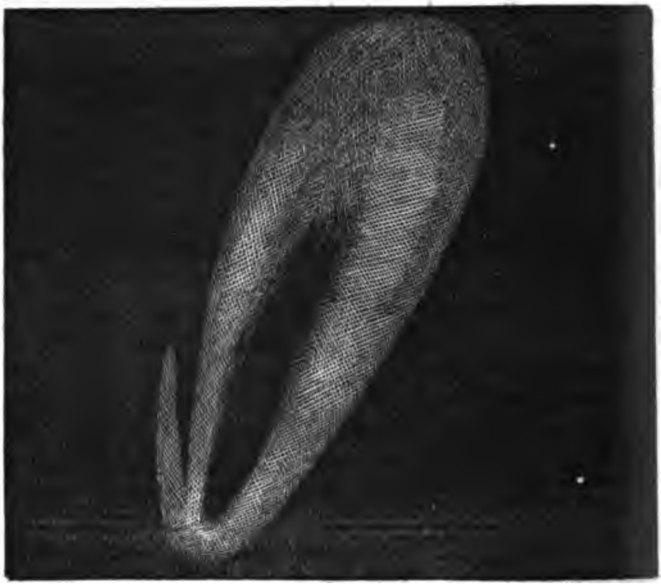

FIG. 167.—SECOND COMET OF 1825.

pole-star on the northern side. The comet of 1680, with a head no larger than a star of the second magnitude, had a tail which covered from 70° to 90° of the heavens; and its actual greatest length was calculated at about 123 millions of miles; so that, if the comet had been in the sun, its tail would have extended nearly 30 millions of miles beyond the earth's orbit. The length of the tail of the celebrated comet of 1811 was about 108 millions of miles; and the diameter of the transparent space between the head and the commencement of the tail, was about half a million of miles. On the other hand, there are several comets, especially those which are only visible with the assistance of a telescope, that do not possess tails; such were the comets which appeared in the years 1585, 1682, and 1763, although that of 1682 is recorded to have been as bright as Jupiter; and such also are the comets of Encke and Biela.

FIG. 168.—COMET OF 1819.

649. With regard to the amount of solid matter contained in these remarkable bodies, and the mode in which this is arranged, there has been considerable difference of opinion; and the variation is probably to be accounted for by an actual diversity in the constitution of different comets. Thus, there are some which appear like collections of vapour, more dense towards the centre, but exhibiting no distinct nucleus, and therefore not entitled to be considered as having the least solidity. Stars of the smallest magnitudes remain distinctly visible, though covered by what appears to be the densest portion of their substance; although the same stars would be completely obscured by a moderate fog,

extending only a few yards from the surface of the earth. But, in other instances, when the nuclei are viewed with powerful telescopes, they have appeared to contain a solid centre; which seemed in one instance about 3250 miles in diameter. The best proof, however, of the very small amount of matter contained in comets, is derived from the complete absence of any perceptible influence produced by them on the movements of the planets; whilst they are themselves affected by these bodies in a very high degree. Thus, the comet of 1770 passed within about six times the moon's distance from the earth, without producing the least influence, even on our tides; yet the revolution of the comet itself is stated to have been retarded by it, to the amount of two days. Had the mass of this comet been equal to that of the earth, its passage so near it would have increased the length of the year by nearly three hours; but as we know that the length of the year was not actually increased by the fraction of a second, it may be proved that the mass of that comet could not have been equal to 1-5000th part of that of the earth. This same comet twice swept through Jupiter's system of moons, without in the least deranging their motions, though its own orbit was completely changed, in the manner and degree already stated (§. 645).

650. The absence of any changes of appearance resembling the *phases* of a planet, also indicates the vaporous nature of comets; for, if they had large solid nuclei, these would reflect the sun's light to us, or would present their dark faces towards us, according to the relative positions of the sun, the comet, and the earth. This is so far from being the case, that we always see the whole head illuminated;—a fact for which there is no other way of accounting, than upon the supposition that, either the comet is self-luminous, or that it is a great mass of thin vapour, susceptible of being penetrated through its whole substance by the sun-beams, and of reflecting these alike from its interior parts, and from its surface. That comets are not self-luminous, appears from the fact, that when they recede from us, they do not retain their brilliancy whilst their apparent size diminishes, as is the case with regard to the sun and stars; but

that they gradually become dimmer and dimmer as they increase their distance from the sun, and at last vanish, merely from the loss of his light, while they still retain a sensible diameter. The most brilliant comets have hitherto ceased to be visible, when about five times as far from the sun as we are; and most of those that have been seen from the earth have their perihelion within the orbit of Mars. It may, therefore, be concluded that comets shine by reflecting the sun's light; and from what has been stated of the extremely small amount of matter they contain, it is evident that "the most unsubstantial clouds which float in the highest regions of our atmosphere, and seem at sunset to be drenched in light, and to glow throughout their whole depth, as if in actual ignition, without any shadow or dark side, must be looked upon as dense and massive bodies, compared with the filmy and all but spiritual texture of a comet."

651. That the luminous part is something of the nature of a smoke, cloud, or fog suspended in a transparent atmosphere, appears from the fact already stated, respecting the transparent interval between the head itself and the portion of the tail that comes up and surrounds it; an appearance analogous to that which we frequently witness in our own sky, of one layer of clouds spreading over another, with a considerable clear space between them. This widely-dispersed condition of the solid matter seems due to the very small attraction which there will be towards the central point, from the absence of solidity there. "If the earth," remarks Sir J. Herschel, "retaining its present size, were reduced by any internal change (as by hollowing out its central parts) to one-thousandth part of its actual mass, its coercive power over the atmosphere would be diminished in the same proportion, and in consequence the latter would expand to a thousand times its actual bulk;—and indeed much more, owing to the still further diminution of gravity, by the recess of the upper parts from the centre." It has been observed that, in Encke's comet, which has no tail, there is a rapid contraction in the size of the nebulous disc as it approaches the sun, and an equally rapid increase as it recedes; and it has been suggested by Sir J. Herschel, that this change may be due to the conversion by the sun's heat,

of some of the materials of the comet, from the state of a visible cloud to that of an invisible gas, and a subsequent return to its previous condition when the heat is withdrawn,—just as we see the vapour of water diffused through the air in the state of mist or fog, rendered transparent by a slight increase of atmospheric temperature.

652. No satisfactory explanation has ever been offered, as to the nature of the luminous train or tail. The common idea is, that this consists of matter which has been left behind, as it were, by the comet during its rapid course, and which remains for some time in the same position, like the smoke from a steamer on a calm day. But this is quite inconsistent with the fact already stated respecting the direction of the tail; for after the comet has passed its perihelion, the tail rather projects before it, than is left behind. That the condition of the tail is in some degree connected with the effect of the sun's heat upon the matter of the comet, appears from the fact, that the size of the tail increases as it approaches him; and that it is much greater on the return of the comet from its perihelion passage, than it is on its approach towards it. Very frequently, comets make their first appearance with little or no train; and yet exhibit one of great length and brightness, whilst they are receding from the sun. That some of their own substance is thus driven off, and dispersed into space through the deficiency of sufficient attraction to draw it again towards the nucleus, further appears from this fact,—that the size and brilliancy of the comets whose return has been observed, are undergoing a sensible diminution with each re-appearance.

653. The want of density in these bodies is further proved by the effect produced on their movements by the resisting medium already mentioned (§. 642). For this medium has not density enough to have produced the slightest perceptible effect upon the movements of the planets; though an extremely trifling change, accumulating through many centuries, would now be recognised with certainty. Yet its resistance shortens the period of Encke's comet by as much as one day in 2500. Thus we may recognise the existence of this medium by its resistance to this

little "whiff of vapour;" just as we recognise the presence of our own atmosphere by its resistance to a feather, although a piece of lead falls through it without showing its effects. On this view of the constitution of comets, which every known circumstance appears to confirm, "we might as well attempt to ascertain how far a cloud which is driven against a mountain will tend to break off the top, as speculate upon any mechanical danger to the earth from contact with a comet. The effect of such a circumstance would be the mixture of its gaseous material with our atmosphere, causing a permanent rise in the mean height of the barometer (though there is no evidence that all the comets put together would have mass enough to produce a sensible effect of this kind); and, if the gaseous matter should condense sufficiently to descend to the lower regions of our atmosphere, some effect upon animal existence, as likely good as bad." Hence we may at once put aside the many speculations which have been offered respecting the operation of comets upon our own globe or upon that of others; and consider it almost certain, that a comet cannot have had any concern in the creation of our planet, and that nothing is to be feared respecting its injury or demolition from such a cause.

"Lo! from the dread immensity of space,
Returning with accelerated course,
The rushing comet on the sun descends,
And as he sinks below the shading earth,
The guilty nations tremble.
Th' enlighten'd few
Whose god-like minds philosophy exalts,
The glorious stranger hail; they feel a joy
Divinely great;—they in their powers exult;
That wondrous force of thought, which mounting spurns
The dusky spot, and measures all the sky;
While, from his far excursion through the wilds
Of barren ether, faithful to his time,
They see the blazing wonder rise anew
To work the will of all sustaining love."
THOMSON.

CHAPTER XX.

OF THE EARTH'S ANNUAL REVOLUTION.

654. It has been shown that, by admitting the earth to have an annual revolution round the sun, as well as a daily rotation on its own axis, we are able to explain all the observed movements of the heavenly bodies; and that on no other supposition could we account for them so simply and satisfactorily. It has also been pointed out, that the phenomenon of the aberration of light (§. 623) gives exactly that *proof* to the supposition, which was wanting to render it positively certain. It will now, therefore, be treated as an established fact in astronomy; and its consequences will be considered in more detail.

655. The orbit of the earth is an ellipse, of which the semi-axis, constituting the *mean* distance (§. 565) of the planet from the sun, is about 95 millions of miles; but when at its *perihelion* (or shortest distance from the sun), the earth is about 1½ million of miles nearer to the sun than this; and when at its *aphelion* (or greatest distance), it is about 1½ million of miles further off than the mean distance. The whole orbit is traversed by the earth in 365 days, 6 hours, 9 minutes, 9½ sec. solar time; that is, rather more than 365¼ *solar* days elapse, whilst the revolution is being completed, so far as respects the earth's position in regard to the *stars*. This period is termed the *sidereal* year; and it consists of about 366¼ *sidereal* days; since, as formerly explained (§. 454), in consequence of the apparent backward movement of the sun amongst the stars, they are about 4 minutes less than 24 hours in coming to the meridian after one diurnal revolution of the earth, and thus gain exactly a day upon the sun during each year. The same effect would be produced by a person's travel-

ling continually eastward, or in the direction of the earth's rotation. When he has completed his circuit of the globe, he will have moved round its axis once more than the earth itself has done; and consequently will have gained a day,—not, however, by the absolute creation of time, but by the shortening of all the other days to make up for it. On the other hand, a person who circumnavigates the globe in the contrary direction, loses a day; for by journeying with the sun, each day is prolonged; and when he has completed his circuit, he will have made one revolution less than the earth itself has done. Hence, supposing that two ships return from voyages of circumnavigation made in contrary directions, on a day which is Wednesday to those who have remained at home, that day will be reckoned as Tuesday by the ship which has sailed westwards, and Thursday by the one that has proceeded eastwards. The missionaries in some of the South Sea islands continue to keep different reckonings, corresponding with the different courses of the ships which conveyed them there.

656. If the orbit of the earth were circular, the motion of our globe would be equable in every part of it, so that the length of each day (that is, of each interval between noon and noon) would be the same. But this is not the case; for the velocity of the earth's onward movement varies considerably in different parts of its orbit, whilst that of its diurnal revolution remains always precisely the same. The mode in which this will operate, is shown in the accompanying diagram. Let A B represent a portion of the earth's orbit at or near its aphelion, and C D a corresponding portion near its perihelion;

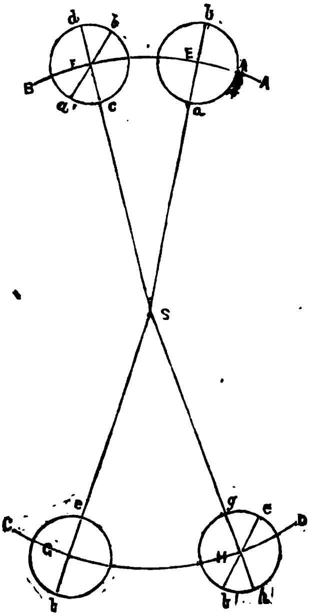

FIG. 169.

then, from the varying rate of movement which is the result of the difference of distance, the earth will occupy the same time in moving from E to F, that it requires to move through the greater length G H. Now when the earth is at E, the sun is shining directly upon the point *a*; and it is consequently noon at that place. But in travelling towards F, the earth rotates on its axis, so that the point *a* is carried towards *b* in the direction of the arrow, and afterwards again into a position corresponding with *a*. But owing to the change in the earth's place in its orbit, it does not then come directly opposite to the sun; for although, when the line *a b* has returned to its original position in *a′ b′*, the earth has actually made one complete rotation on its axis, as is evinced by the direction of *b′* towards the same stars towards which *b* pointed, it is obliged to turn still further before the point *a′* can again be presented directly to the sun, which it does not do until it arrives at the position *c*. Hence the sidereal day, or the time which elapses between either of the points *a* or *b* quitting their first position, and returning to it again in *a′ b′*, is the real measure of the earth's rotation; but for obvious reasons, it is more convenient to adopt as our standard the solar day, or the time which intervenes between any point *a* quitting its first position, and returning to the same position as regards the sun, which it does not do until it reaches *c*.

657. Now in like manner, as the earth changes its position from G to H, it makes a corresponding rotation on its axis, so that the line *e f* comes into the position *e′ f′*, which is the same in regard to the stars; and for this movement precisely the same time is required as before. But before the point *e′* can again return to its original direction in regard to the sun, it must be carried by the earth's rotation, to *g*. Now it will be observed that, as C D is nearer than A B to S, the sun, the movement of the earth in the former part of the orbit will be faster than in the latter; and consequently a larger amount of it will be traversed in the same time. The result of this will evidently be, that, as the earth changes its place in reference to the sun, more between G and H than between E and F, the excess of the solar day over the sidereal will be greater in the second case than in the first;—

or in other words, the space between e' and g, which the earth has to fetch up (as it were) in order to bring e' again opposite to the sun, will be greater than the space a' c, which the earth has to move for the same purpose in this other part of its orbit. Consequently the interval between noon and noon will be longer than the average in the second case, and shorter in the first. Consequently, as the clock is made to go an *average* day, or in other words 1-365th part of the number of whole days in the year, the sun will sometimes cross the meridian before the noon of the clock, and sometimes after.

658. There are four days in the year in which the noon of the sun and the noon of the clock correspond, or very nearly so; these are the 15th of April, the 15th of June, the 1st of September, and the 25th of December. After Christmas day, the sun begins to be behind the clock (the earth being then in the most rapid motion), and the difference increases, until it amounts to about 14½ minutes; after which it progressively decreases, until the two correspond. Between April and June, the sun is before the clock; but the greatest difference is less than 4 minutes. Between June and September, the clock is before the sun again; but the greatest difference does not much exceed 6 minutes. And lastly, between September and Christmas, the sun is again before the clock, and this time to the extent of nearly 16½ minutes. This difference, the extremes of which thus amount to nearly 31 minutes, is known as the *equation of time;* and its amount for every day in the year, is set down in most almanacs, so that in keeping a clock by the sun, the proper allowance should be made.

659. The hour of noon may be ascertained with a considerable degree of exactness, without a transit instrument, by erecting some fixed mark which shall throw a pointed shadow; if a line be drawn from it through the point of the shadow at the exact time of noon, as fixed by a good clock (the proper allowance being made for the equation, if any) the point of the shadow will always fall in some part of that line at noon, and will thus enable the clock to be regulated much better than by an ordinary sun-dial. The more distant the point of the index is from the surface on which its shadow falls, the quicker its

shadow will move; and consequently, the more accurately may the time of the sun's passing the meridian line be noted. Such an index may be very well constructed in any ordinary room having a southern aspect, by fixing a narrow slip of card or other opaque material on the window, and drawing the meridian line on the floor; or, which is still better, making the index to consist of a piece of thin metal, having a slit in its middle, through which a narrow beam of light may pass; the metal will throw a deep shadow, and the beam which issues from the midst of it will play over the index-line, in such a manner that the time of the sun's passing the meridian may be noted, to within a few seconds of the truth,—a degree of exactness quite sufficient for all ordinary purposes. In some cathedrals, such a line has been marked along the floor, by marble of a different colour from the pavement, inlaid, so as not to be effaced; and the beam of light has been admitted through a narrow chink in the wall at a great height.

Of the Seasons.

660. If a globe like the earth receive light from a large luminary, such as the sun, it is evident that the light will fall upon half of its surface at once, and that the other half is in the dark. This may be easily proved by the simple experiment of holding a small globe, an orange, a ball of worsted, or anything that has a globular form, near a lamp or candle, no other light being allowed to fall upon it at the same time.—But the part of the globe which will be illumined, will depend upon the manner in which it is held. Thus, suppose in the first instance that it be held on a level with the lamp,—the light will then fall directly on its equator, and the illuminated hemisphere will just extend to each pole. Now if the globe be made to turn round, as by suspending it from a string passing through its poles, it will be seen that every part of the globe is turned towards the light during exactly half its revolution; and if we carry our globe in a circuit round the lamp, causing it to continue rotating at the same time, the same will occur in every part of its revolution. But if we hold the globe rather *above* the lamp, the under

part of it will receive more light, and the upper less; and on making it revolve, we shall see that the south pole and the parts surrounding it, are continually enlightened, whilst the north pole and its neighbourhood are in constant shadow. On the other hand, if we lower our globe a little, so that the light falls more upon the upper part of it, and then make it revolve, the north pole and the parts near it remain constantly in the illumined hemisphere, whilst the corresponding parts about the opposite pole remain in continual shadow.

661. Hence we see that, if the axis of the earth were so directed, that, during the whole of its annual revolution, the rays of the sun fell directly upon its side, the illumined hemisphere would extend to each pole alike, and the length of the days and nights would be constantly the same: and a like quantity of the light and warmth of the sun would fall upon any point of the earth's surface, during the whole of its annual revolution, so that there would be no variety of seasons. Of all the changes which are sources of so much benefit and happiness to the living creatures that people our globe, there would be none, if the earth's axis were perpendicular to the plane of its orbit round the sun. Its simple inclination to the amount of about 23½ degrees, and its continuance in the same direction during the whole of the earth's circuit round the sun, is enough to convert the uniform monotony of an unvarying state, into the pleasing variety of spring, summer, autumn, and winter. For it will easily be perceived to be immaterial whether, keeping the axis upright—as in the experiment just referred to—we cause the orbit to rise above the level and sink below it, alternately; or whether, keeping the orbit level, we slope or incline the axis towards it, so as to turn, sometimes the north pole, sometimes the south, and sometimes both equally, towards it. In Fig. 170 it is shown

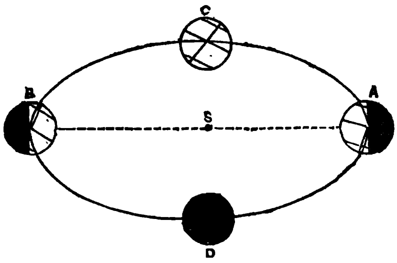

FIG. 170.

how the change in the seasons, and in the length of the day and night, is thus produced. This figure represents the orbit of the earth, and the earth itself, as seen in perspective in four different positions. The axis, terminated by the two poles, is shown to point, in all, in the same direction; and in all, the illuminated portion of the earth is shown, as it would appear to a spectator looking from the nearest side. Thus at A and B, exactly half of the illuminated face is seen; whilst at C, the whole of it is turned towards the observer, and at D it is entirely turned away.

662. Now, from the inclined position of the earth's axis, it is seen, that in the position A, the sun does not shine directly upon the equator, but upon a point below it; and this point is at just the same distance from the equator, as the poles are from the vertical line, namely 23° 28′. As the earth rotates, every point at that distance from the equator successively passes beneath the sun, which, to the inhabitants living on this circle (termed the Tropic of Capricorn) appears directly above their heads at noon-day. Again, it is seen that the south pole, and the whole surface included within a circle drawn at a distance of 23½ degrees from it (termed the Antarctic circle) is in the enlightened hemisphere; and consequently, the earth's rotation produces no night to them, but the sun remains above the horizon during the whole 24 hours; and mid-day is not to be distinguished from mid-night, except by the greater height to which he rises in the sky, and by the part of the horizon above which he is seen. On the other hand, the north pole, and the space included within the corresponding (or Arctic) circle, remain, during the whole daily rotation, in the unenlightened hemisphere; and the inhabitants of these regions lose sight of the sun for many days and weeks together. At all parts of the earth which are to the north of the Tropic of Capricorn, the sun will rise 23½ degrees lower in the sky at noon-day, than he does when shining on the equator; whilst to all who are on the south of it, he appears to rise higher by the same amount. It will also be plain that, as by far the larger portion of the southern hemisphere is in the illuminated half, the days will be long;

whilst in the northern hemisphere they will be short, a large proportion of it being on the darkened side. The shortness of the days, and the low elevation which the sun attains in the sky, together prevent him from exerting his genial influence upon the northern hemisphere; whilst it is fully bestowed upon the southern. Hence in this position of the earth, it is summer in the southern hemisphere, and winter in the northern.

663. At B, however, it is just the reverse; for the sun is now shining directly upon the Tropic of Cancer, a circle 23½ degrees north of the equator; consequently, the north pole is exposed to his continued influence, whilst the south pole is withdrawn from it. The days are longer in the northern hemisphere; and in all parts of it the sun rises 23½ degrees higher in the sky, than when he is shining on the equator; so that it is summer in the northern hemisphere, and winter in the southern. But, in the positions C and D, the earth's axis is neither turned away from the sun nor directed towards him; so that the poles are at an equal distance from him, and the illuminated face divides each hemisphere equally. At these periods, the days and nights are equal all over the globe, and they are termed the *equinoxes;*[*] whilst the extreme summer and winter positions A and B are called the *solstices.*[†] The days and nights are always equal on the equator; since this line is always divided equally by the boundary between the illuminated and unilluminated halves; which can be said of no other circle that can be drawn upon the earth's surface.

664. Owing to the fact, that in our winter, the earth is in the part of its orbit nearest to the sun, and its motion therefore more rapid than in the summer, the interval between the *autumnal* and *vernal* equinoxes, which occur on the 21st of September and 21st of March, is nearly 8 days shorter than that which elapses between the vernal and autumnal. Hence it is that our month of February is so much shortened; and that there are only three months of 31 days in the former period, whilst there are four in the latter.

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[*] Meaning *equal nights.*

[†] Meaning that the sun appears to be stationary at these points, neither rising higher nor sinking lower, in any considerable degree, for a few days.

665. The points of the earth's orbit at which the equinoxes occur (namely, the nodes at which a plane passing through the equator would cut that of the ecliptic) do not always remain the same; but are in fact themselves undergoing a regular revolution, in a direction contrary to that of the earth's motion in its orbit, which will require a period of 25,868 years for its completion. Hence the equinoctial points come, as it were, to meet the earth; and as our year is measured, not by a sidereal revolution of the earth (§. 655), but by the re-commencement of the same series of seasons, which must take their date from the equinoxes and solstices, our ordinary or *tropical* year (as it is scientifically termed) is shorter than the sidereal year by 20 min. 20 sec.; and thus it is reduced to 365 days, 5 hours, 48 min., and about 49½ sec. This curious phenomenon is called the *precession of the equinoxes;* and it may be regarded as resulting from a kind of very slow conical revolution made by the earth's axis itself, much resembling that which the spindle of a top or tetotum makes when just beginning to be unsteady. This revolution, which occupies the immense period just mentioned, gives to the equator a sort of tilting motion, such as the flat surface of a tetotum has in the case just alluded to; and this will manifestly produce a continual change in the position of the points at which it cuts the plane of the ecliptic.

666. This change may be reckoned among those *perturbations* already referred to (§. 582), which, although never ceasing to take place, do not increase, but keep within a certain limit. Its cause is the attraction of the sun for the mass of matter which is about the earth's equator; and its effect is to occasion a gradual change of apparent place in all the heavenly bodies, as reckoned from that point of the ecliptic at which the vernal equinox occurs. When the place of the stars was first compared with that of the sun, it was observed that the vernal equinox took place as the sun enters the constellation Aries; but it now occurs when the sun has reached a point in the Zodiac thirty degrees to the west of Aries, though, for the sake of convenience, astronomers still speak of that point as the commencement of Aries. One of the most remarkable changes in the apparent place of the stars, is that of the bright star in the Lesser Bear,

which, being nearly in the place towards which the axis of the earth is at present directed, we call the Pole-Star. At the time of the construction of the earliest catalogues, however, this star was 12° from the pole; it is now within $1\frac{1}{2}°$ of the real pole of the starry sphere, and it will approach to within half a degree; after this it will again recede, and others will come into its place. When about 12,000 years shall have elapsed, the star α Lyræ, the brightest in the northern hemisphere, will come nearly into the position at present occupied by the Pole-Star.

The Calendar.

667. The regular successive change in the seasons, appears to have suggested, at a very early period, the establishment of that division of time which we call a *year;* and the ancient Egyptians fixed 365 days as its length. It is said that they were led to this, by observing the periods at which the shadows thrown by their obelisks at mid-day, were at their greatest and least lengths. The greatest length of the shadow at noon would of course occur, when the Sun attains the least height in the sky, which is also the period of the shortest day; while the shortest shadow will be thrown, when the Sun's height is the greatest, which is at the time of the longest day. Hence, by marking the points of either the longest or shortest shadows, and observing the number of days which elapsed between the times when they recurred, the length of the year might be determined; and it is recorded that they fixed it, by a series of such observations,* at 365 days. This year they regarded as consisting of 12 months, each composed of 30 days; and the 5 remaining days were added at the end of these. The Romans, however, appear to have taken the Moon's revolution as their standard; and made the year to consist of 13 lunar months, or 355 days, adding other days as they seemed to be wanted to bring up the year to the standard of the seasons. In the time of Julius Cæsar, the error had amounted to as much as 90 days; and when he undertook the reformation of the Calendar, he was obliged to make

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* Any *single* observation would be liable to error; since the sun's declination alters very little for two or three days together, at the time of the solstices (§. 663).

the year 46 B. C. consist of 455 days, that the next might commence properly. At that time it was known, that the length of the solar year is about 365¼ days; and it is to him that we are indebted for the neat contrivance, of introducing an *intercalary* day every fourth year, so that the whole number of days in four years is not 1460, but 1461—which would correspond exactly with the reality, if the excess of each year above 365 days were precisely a quarter of a day. It was Julius Cæsar, also, who adopted the plan of commencing the year with the 1st of January. Before this reformation, it had dated from the vernal equinox; and he seems to have fixed the 1st of January as the commencement of the year 46 B. C., merely because it was the day of the first new moon after the preceding winter solstice. This mode of reckoning is termed the Julian Calendar.

668. It is evident that, as the year adopted for the standard of the Julian rule was 1-4th of a day above 365 days, and the real year is not so long by about $11^{m}\ 10^{s}$ (§. 665), the intercalation of a day in every four years was an *over* correction; and it was perceived, after the lapse of nearly 1500 years, that the equinoxes no longer correseponded with the days on which they ought to have invariably occurred, but took place several days before the proper time,—the real year being thus in advance of the Calendar year. From this it was evident, that the Julian rule must be in some degree altered; and the reformation was made by Pope Gregory XIII. in the year 1582. In order to bring the calendar and the sun together, it was then necessary to omit 11 days (which was the number that had been wrongly inserted); and a rule was made for its future regulation, which will serve to prevent any similar error for many ages to come. This rule will be immediately explained. The Gregorian Calendar was immediately adopted in Catholic countries; but in Britain, the error was suffered to continue and increase, until the middle of the last century, when it amounted to 11 days, which were struck out of the month of September, 1752. It was not until this period, that the year was made to date from the 1st of January; and the two alterations together constitute the difference between the old style and the new style. The

date we should assign to any previous event, which happened in the months of January, February, or March (up to the 21st), depends upon the *style* we adopt. Thus the beheading of Charles I., which took place on the 29th of January, was in the year 1648 old style, since that year did not close until March 21; but it would be in the year 1649 new style, and as such it is usually reckoned. Russia is now the only country in Europe in which the old style is still adhered to; and the difference between the European and Russian dates now amounts to 12 days.

669. The Gregorian rule for the insertion of the intercalary day consists of three distinct parts. This day is (1) to be added, as by the Julian rule, to every fourth year; except (2) when that year is the commencement of a century; but (3) if the number of that century is divisible by 4, the addition is still to take place.—This rule works thus. We ascertain the *leap*-year (1) by dividing the number of the year (or, which is the same thing, the two last figures of it) by 4; if there is no remainder, it is a leap-year; but if there be a remainder, it shows the number of years that have elapsed since the last leap-year. For instance, when the number of the present year, 1843, is divided by 4, the remainder 3 is left; by which we know that 3 years have elapsed since the last leap-year. The next year, 1844, will be a leap-year, that number being divisible by 4 without a remainder.—But as this correction is too great (2), the first year of the century is *not* made a leap-year, so that there are only 24 years of 366 days in the century, instead of 25.—But this correction is a little too great the other way, reducing the number of leap-years too low; and therefore (3) every fourth *secular* year* receives the additional day. Thus, although the years 1700, 1800, and 1900 would not be leap-years, as by the Julian rule they would have been, the year 2000 will be, since the number of its century (20) is divisible by 4. By following this simple rule, a vast period must elapse before the calendar can be again disturbed. For it is easily calculated that 10,000 Gregorian years will consist of 3,652,425 days; whilst 10,000

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* That is, a period of a century, from the Latin *sæculum*, an age.

real years will consist of something less than 3,652,422½ days; so that the difference between the two periods is very little more than 2½ days, which is almost exactly equivalent to one day in 4000 years. Even this might be corrected, if it ever became necessary, by omitting, every 4000th year, the intercalary day which by the Gregorian rule is inserted every 400th year; but the rule, as it stands at present, will be probably sufficient for all human purposes.

CHAPTER XXI.

OF THE MOON.

670. The shortness of the distance between the Earth and the Moon, as compared with the vast distances of all the other heavenly bodies from our globe, is a sufficient reason why she should appear to us to cover the largest surface of the sky, although she is really the smallest of all the luminaries which we can discern with the unaided eye. And for the same reason, we are better acquainted with her constitution, than we are with

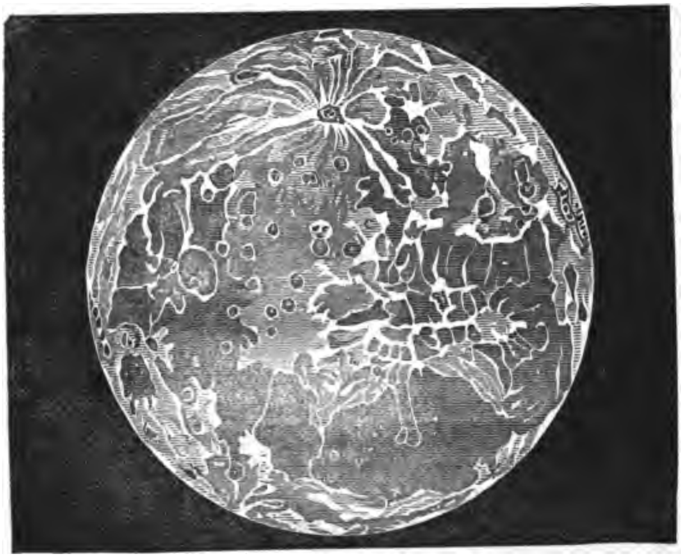

FIG. 171.—APPEARANCE OF THE MOON, AS SEEN THROUGH A TELESCOPE.

that of any other of the heavenly bodies. A well-constructed telescope, magnifying a thousand times (and there are instruments of higher power than this), enables us to see the surface of the Moon, as if we were situated at no more than 237 miles above it. With an instrument of much inferior power, it can be plainly seen that the surface is extremely unequal,—that there are, in fact, high mountains and deep valleys in the moon,—and that many of the mountains are so *volcanic* in their aspect, that it is difficult to believe them to be anything else. These mountains are best distinguished, by observing the border of the moon which is turned away from the sun, and which, during the time of the moon's increase, is gradually receiving the sun's light; this border is not smooth, like the other, but presents a number of little islets of light, separated from the remainder of the luminous surface by a dark interval; but as the illuminated surface extends, they gradually become united with it, the dark interval disappearing. Now, this interesting phenomenon can be nothing else than the illumination of the tops of the mountains by the sun's rays, whilst the valleys and level ground between them remain in shadow; and it corresponds exactly with the appearances which we may witness on the surface of our own earth, by watching a sunrise in a hilly country.

671. As long as they remain near the illuminated edge, these mountains cast distinct shadows, owing to the obliquity with which the sun's light then falls upon them; but at the time of full moon, when the sun's light falls directly upon the whole of the face which is turned towards us, these shadows are no longer to be seen. By measurement of the length of these shadows, it has been calculated that the height of some of the mountains in the moon is about $1\frac{3}{4}$ miles; which bears a greater proportion to the diameter of the moon (2160 miles), than the height of the loftiest mountains upon our own globe does to *its* diameter. There are several large tracts, which are perfectly level, and which would seem, therefore, to have an *alluvial* * character;

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* This is the geological term for those deposits which have evidently, from the flatness of their surface, been formed by the action of water.—See TREATISE ON GEOLOGY.

but nothing like an extensive surface of water has ever been discovered. The absence of any large collection of water is also proved, by the absence of anything like clouds floating over the surface of the moon; and by the perfect sharpness and clearness of her edge. If an atmosphere existed round the moon, some manifestations of it could not fail to be discovered, when her disc passes over the sun or the stars. Now the day and night, at any spot of the moon's surface, are each (as will be presently explained) of a little more than a fortnight's duration; and consequently, there will be an uninterrupted sunshine for the whole of that period, succeeded by night of equal length, cheered only by the brilliant *moonlight* which will be reflected with like constancy from the surface of our Earth. The *day* will be fiercely hot; whilst the *night* will be chillingly cold; and the constitution of living beings, whether plants or animals, adapted to such a climate, must be very different from ours.

672. The Moon revolves round the Earth in an elliptical orbit, at a mean distance of about 237,000 miles; and the excentricity of this orbit is such, that she is about 26,000 miles nearer to the earth at one time than at another. When at her nearest point, she is said to be in *perigee* (from two Greek words meaning *near the earth*); and when at her greatest distance from it, she is said to be in *apogee* (from two Greek words meaning *from the earth*). The line joining the extreme points of her orbit does not constantly point to the same part of the heavens, as is the case with the similar line passing through either of the orbits of the planets; but it is continually varying (§. 680). The moon's orbit is inclined to that of the earth 5° 8′ 47″; and the line joining the nodes also has a regular movement, instead of constantly pointing in one direction,—a circumstance which has great influence over the succession of eclipses (§. 680). These variations are among the *perturbations* resulting from the Earth's attraction.—Although the Moon is said to revolve about the Earth in an elliptical orbit, yet this would be strictly true only if the earth were at rest, and her actual path is very different; for, as the earth is at the same time travelling round the sun, and as she is carried with him by the same forces, her line of

movement is made up, as it were, of *his* large ellipse and her small one combined; and it would be represented by drawing a wavy line along the earth's orbit, sometimes passing to a short distance on one side of it, then crossing it, and bending as much the other way.

673. The Moon completes her revolution round the Earth,—that is, she returns to the same place among the stars,—in about 27 days, $7\frac{3}{4}$ hours; but the interval between new moon and new moon, or between full moon and full moon, is about 29 days, $12\frac{3}{4}$ hours. The reason of this difference is, that the times of new and full moon depend upon the position of the moon in regard to the sun; the former happens at her *conjunction*, the latter at her *opposition*. Now supposing the sun and moon to have been in conjunction at a given time in a particular part of the heavens, *she* will return to the same point in about $27\frac{1}{3}$ days, but *he* will have left this situation in the mean time, and will have performed about 1-13th of his annual circuit amongst the stars (§. 547). The moon, therefore, must pass through this space, and rather more, before she can overtake him and come into conjunction again; and to do this, occupies about 2 days, 5 hours. This may be familiarly illustrated by the movement of the hands of a clock or watch, of which the minute-hand may be compared with the moon, and the hour-hand with the sun. They are together, or in conjunction, at 12 o'clock; and, by 1 o'clock, the minute-hand has performed a complete revolution; but it does not again come into conjunction with the hour-hand until $5\frac{5}{11}$ minutes past 1, at which time the two are together as before. The length of the actual revolution of the moon round the earth is called its sidereal period, or that of its *periodic* revolution; whilst the interval between two new or full moons, is termed that of its *synodic* revolution.

674. During each revolution round the earth, the moon turns exactly once round on her own axis; the consequence of which is, that the same face is always presented to *us*, whilst different sides are successively turned towards the *sun*. It is not easy to understand, how a single rotation of the moon on her axis will produce this effect; but the fact is easily proved by a

simple experiment. Take any object, a book, a box, or an inkstand, and carry it in a circle round that other; it will be found that, if no twisting motion be given to it by the hand, different sides of it will be progressively turned towards the central body; and that it will be necessary, in order to keep *the same* side towards that body, to give it a kind of twist, as it is moved round, which will in fact turn it once round upon its own axis during each revolution. It will also be observed, that this same twist has the effect of turning *different* sides towards any body at a distance. If the moon had no such rotary movement, her different sides would be turned, one after another, to the earth; but the same face would be constantly presented to the sun; so that only the inhabitants of that hemisphere would enjoy his light and warmth; whilst those of the other side would exist in perpetual darkness, unless when faintly illumined by the light reflected by our earth. Though it has been said, that we always see the same face of the moon, this is not strictly correct; for we sometimes have one side a little more turned towards us, sometimes the other, in consequence of the varying rate of the moon's motion in her orbit, which does not always correspond with that of her rotation on her axis; whilst we sometimes see a little further over her upper edge, sometimes a little further over her lower, in consequence of the inclination of her orbit to the ecliptic, which causes her to be either raised above or sunk below its plane, during each revolution. This slight apparent movement of the moon, giving rise to a change in her aspect, is termed her *libration.**

Eclipses.

675. Eclipses, like comets, were formerly objects of popular terror; and they still are so among savage and half-civilized nations; but it is now universally known, among all those to whom the light of science has extended itself in even a very faint degree, that these phenomena are but the necessary conse-

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* The term *libration* means *balancing*; and the idea which it was intended to express, was that of a kind of oscillation to one side and the other, like that made by a balance when coming to rest.

quences of the laws of nature, and that they can be predicted with as much accuracy as the return of day and night. This was effected even by the Chaldeans of old, as it has since been by the Chinese; in both there was an equal ignorance of the *cause* of eclipses; but attentive observation, prolonged through a great number of years, was sufficient to enable them to foretell eclipses with tolerable accuracy, since (as we shall presently see) the same *set* of eclipses recurs, with little variation, every eighteen years and a half.

676. When the Moon, in her monthly revolution, passes directly between the earth and the sun, she necessarily hides from us a part of the sun's light, being an opaque body through which it cannot pass. Familiar observation teaches us, that a very small body may completely obscure a very large one, provided that the former be close enough to the eye. Thus, with a sixpence held near the eye, we may cover the whole disc of the sun or moon. Hence the moon, though so extremely small in comparison with the sun, as not to bear the proportion of a moderate pin's head to a globe two feet in diameter, is able to obscure the whole of his light, if situated at her point of least distance from the earth, directly between the sun and any spot on its surface. On either side of this spot, a portion only of the sun's disc will be obscured; and as we proceed further and further from it, the obscuration is less and less, until it ceases altogether. This will appear from the accompanying diagram, in which S represents the sun, L the moon, and E the earth. If we draw lines from the edge of the sun's disc so as to touch the corresponding edges of the moon's, we shall find that they will meet in a point a little within the earth's surface; these lines will be the borders of the deep shadow produced by the moon; for in all the space which they include, the sun will be totally obscured. But if we draw lines

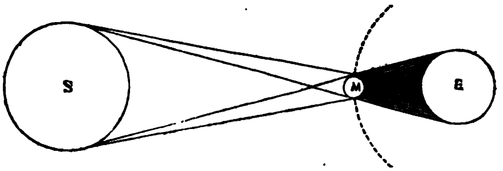

FIG. 172.—ECLIPSE OF THE SUN.

from each margin of the sun's disc, along the opposite edges of the moon's, we shall find that these include a much larger space, which is that where a fainter shadow will fall, in consequence of the partial obscuration of the sun. The deep shadow is termed the *umbra;* and wherever it falls, there will be a *total* eclipse of the sun. The fainter shadow is termed the *penumbra;* and wherever *it* falls, there will be a *partial* eclipse of the sun; more of his disc being hidden from those who are near the borders of the umbra, and less from those who are near the edges of the penumbra. Hence no eclipse of the sun is *total* over more than a small spot on the earth's surface; but it is *partial* over a much larger extent.

677. As the moon passes every month through that part of her orbit which lies directly between the earth and the sun, the question naturally arises, why a solar eclipse does not take place at every new moon. The answer to this is very simple. If the moon's orbit were on the same plane with that of the earth, this *would* occur; but it is inclined at an angle of rather more than 5°; consequently, when she is at any considerable distance from the nodes, her position at the time of conjunction is not exactly in a line joining the earth and moon, but either above or below it; and a solar eclipse can only take place when she is at or near one of her nodes, in this part of her revolution (§. 561). If she be *at* or *very near* her node, her centre will be in a line joining that of the sun and some spot on the earth's surface; and consequently her *umbra* will fall upon it, and the eclipse will be total at that point. But it more frequently happens, that she is at such a distance from her node, that the point of her umbra falls either a little above or a little below the earth; and hence the eclipse is nowhere more than partial. Moreover, if the moon should happen to be at her greatest distance from the earth, under circumstances at which a total eclipse would have otherwise occurred, the point of her umbra will not reach the earth; and consequently she will not completely cover the sun's disc, but will leave a ring of light around, thus producing what is termed an *annular* eclipse.

678. A solar eclipse is, of course, only visible on that side

of the earth at which the sun himself is seen; hence of all the solar eclipses which actually occur, those that are visible to some of the inhabitants of one hemisphere will be probably about half; whilst those that are witnessed by the inhabitants of a particular spot on either hemisphere will be comparatively few. Consequently, although there are seldom less than two solar eclipses in every year, they seem to be rare phenomena; and it is still rarer for an eclipse to be either total or annular, on account of the number of different conditions which must concur to produce these interesting spectacles. The apparent diameter of the moon, when the greatest in consequence of her proximity to the earth, only exceeds that of the sun by about 1½ minute of a degree; consequently, a total eclipse cannot last a longer time at any place, than is requisite for the moon to travel through this space, which is equivalent to about 3¼ minutes of time. This period is sufficiently long, however, to produce a very striking effect upon the animated creation; birds, cattle, horses, and even men, experience a sensation of horror which can scarcely be accounted for; and the return of light gives a positive feeling of relief.

679. The Earth, like the moon, projects a shadow behind it; and the umbra of this shadow, in consequence of the earth's greater size, is a much larger cone, the point of which extends to 800,000 miles beyond the earth, and thus reaches far beyond the orbit of the moon. In the accompanying diagram, the limits of the earth's umbra and penumbra are laid down, precisely as in the case of the moon in the last Figure; and it is obvious that, when the moon is in opposition, if she be at the same time at or near one of her nodes, she will pass into the earth's shadow,

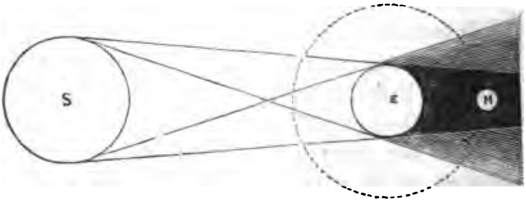

FIG. 173.—ECLIPSE OF THE MOON.

and will thus be eclipsed by the interruption of the sun's light. As the earth's shadow is so much larger than the moon's, it might be supposed that the moon will be eclipsed by the earth much more frequently than the sun by the moon; and this, to an inhabitant of the moon, must be the case. But viewing the moon as we do from a distance, we only see her eclipsed, when she enters the earth's *umbra;* for, so long as she is only in the *penumbra*, she suffers a general diminution of light, without any portion of her disk being completely cut off from the sun's rays, which only happens when it is within the umbra. The moon is totally eclipsed, when she passes completely into the earth's dark shadow; and at that time, the sun would be completely eclipsed to an observer upon any part of the moon's surface,—the earth's umbra being sufficient to cover it all, instead of being confined to a mere spot, as is that of the moon upon our globe. Indeed it requires two hours for the moon to move through the broadest part of the earth's shadow; and she may, therefore, remain totally eclipsed for that period. Her disc is seldom, however, completely obscured; for some of the solar light generally reaches it, through the refracting influence of our own atmosphere.

680. It has been mentioned, that the line joining the nodes of the moon's orbit does not continue to point in the same direction; but that it moves backwards (or in direction contrary to the moon's revolution) every year; and consequently, when the moon has travelled once round the sun in attendance upon the earth, her orbit has passed its first position; and, if its node was originally opposite the sun at the moon's conjunction or opposition, it will not be so again, when the earth and moon have returned to a position in their respective orbits which is otherwise the same. The series of eclipses becomes, therefore, different for each year, during a considerable period; but the same series recurs, with little variation, after an interval of 6585 days, or 18 years and 10 days. For in that period there are exactly 19 synodic revolutions of the line of the nodes;—that is, each node has passed between the earth and the sun 19 times. And in the same period, there are exactly 223 synodic revolutions of

the moon, or lunations; so that the moon returns, after that interval, into the same place with regard to the sun, the earth, and the nodes of her orbit, that she had at first; and the same series of eclipses will recur with extremely little variation. The line of the greatest and least distance of the moon from the earth (which is called the line of the *apsides*) also revolves once in about 9 years, or twice in this cycle of 18 years, so that the moon returns to the same position with respect to her distance from the earth, as well as with regard to the conditions just mentioned.

Tides.

681. The ocean covers more than half the globe of the Earth; and this large body of water is in continual motion. With a few exceptions, arising from local peculiarities, the surface of the water at any point rises and falls twice within each 24$\frac{3}{4}$ hours; and this alternate rise and fall occasions an almost incessant current, which is more powerful, however, in narrow channels than in the open sea. These phenomena are easily explained upon the general principle of mutual attraction. Neither the Sun nor the Moon can act upon the solid parts of our globe, so as to change their place, in any other way than by moving the entire mass. But they can draw up the water towards themselves; and in this manner they produce a considerable change in its level. Notwithstanding the enormous size and attractive force of the sun, as compared with that of the moon, his influence over the ocean is reduced by his distance to not more than a third of hers; and therefore the rise of water occasioned by the moon's attraction, is that which we have chiefly to consider as the cause of the tides. The manner in which this operates is shown in the accompanying diagram. Let *a b c d* represent the earth; and let *e* represent the moon. Then as the attraction of the moon for the water at *d* is greater than for the water at the more distant parts *a* and *c*, and greater also than for the mass of the earth itself (since the attraction may be esti-

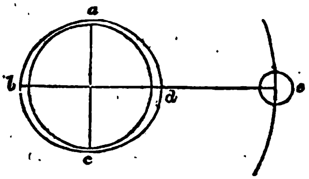

FIG. 174.

mated as operating upon the earth's centre), the water will be drawn up into a heap at *d*, producing a high tide there. As the earth revolves in 24 hours, every part of it would be thus exposed once to the influence of the moon, in the course of a day and night; but in the mean time, the moon has changed her position by travelling onwards in her orbit; so that the period which elapses between the times, when each part of the earth passes directly beneath the moon and again becomes opposite to her, exceeds 24 hours by about 50 minutes.

682. We can easily understand, then, why *one* high tide should occur on every part of the Earth's surface, at intervals of $24^h\ 50^m$; but it remains to be explained why there should be *two* during the same period. The moon's attraction for the water at *d*, exceeds its attraction for the mass of the earth, on account of the difference in their distance from *e* of the point *d* and of the earth's centre; but just in the same proportion, does the attraction of the moon for the mass of the earth, as exercised upon its centre, exceed that which it has for the water at *b*; consequently the earth is drawn away from it (as it were), or, in other words, the water is left behind, and rises into a heap, just as it does at *d*. Hence in whatever part of the earth there is a high tide, there is a corresponding high tide on the opposite side; whilst there will be a drawing off of the water from the points *a* and *c*, producing low tide there. Hence as the earth makes its daily revolution, every portion of its surface passes under two points of high tide, and two of low tide; but its tides are about 50 minutes later each day, for the reason already specified.

683. Now it is when the Sun's influence is joined to that of the Moon, that the tides are raised to their greatest height, and that their ebb is proportionally low; they are then called *spring* tides. This occurs at new and full moon; for in either of these positions the sun, moon, and earth have their centres nearly in the same line; and consequently the sun and moon are both acting to produce high water in the same points. But when the moon is in her quarters, she will be causing high water, where the sun's tide would be producing low water; consequently her

influence will be partly neutralized by that of the sun. The tides will then neither rise so high, nor fall so low; and they are called *neap* tides. The sun's attraction is capable of raising the level of the water about 2 inches for every 5 inches that it is raised by the moon's influence; and consequently the rise, when both are acting together, as at spring tide, will be to the rise at neap tide, when they are acting in contrary directions, as 7 to 3.

684. The highest tide does not take place at any point, however, exactly when the moon is on the meridian of that point, but at least three hours afterwards. This is occasioned by the friction and inertia of the water itself, and by the various obstructions it meets with; by which the wave is prevented from travelling round the earth nearly so soon as it would do, if the moon's attraction were not thus opposed. Hence, though the tide-waves follow one another at regular intervals of $12^h\ 25^m$, each individual tide-wave may be several days in travelling through all the parts over which it extends itself. Thus it is said that in the river Amazon there are at the same time 7 high and 7 low tides succeeding each other. If we trace the tide-wave that comes to Britain from the German Ocean, we shall find that, if it produces high water at Dover at 12 o'clock, it will not arrive at London-bridge until 51 minutes past 2, though it will have reached Brighton at 36 minutes past 12. It will occupy more than 3 hours more to arrive at Falmouth; and 2 hours more still to reach Bristol; so that the travelling of the tide-wave from Dover to Bristol really occupies just 8 hours.

685. The height to which the water rises in any place, depends, like the time, upon local circumstances. Thus in lakes there are no tides, because their surface is so small that it is all equally attracted by the moon. Neither are there perceptible tides in the Mediterranean, nor in the Baltic; because these inland seas are in the condition of great lakes; the openings by which they communicate with the open ocean being so narrow, that they cannot receive from it, in so short a time, a quantity of water sufficient to make any great alteration in their level. On the other hand, in the Bristol Channel, which has a wide mouth

like that of a funnel, the tides are remarkably high; the difference in the level of high and low water at spring-tides being often 50 feet perpendicular; and at Annapolis, in the Bay of Fundy, the tide is said to rise 120 feet.

Phases of the Moon.

686. Although the Moon, during her monthly revolution round the Earth, always presents the same face towards us, yet that face undergoes a series of remarkable changes in the degree of illumination which it exhibits at different parts of the circuit. Thus, when the Moon is in conjunction,—or in a line with the Sun, as seen from the Earth,—the face turned towards us is entirely dark; whilst this same face is brightly illumined, when she is in opposition,—or at the point in her orbit most remote from the Sun; and various degrees of this surface are dark or luminous, as she moves from one of these points to the other. This fact so plainly indicates that she does not shine by her own light, but by light reflected from the Sun, that many of the ancient astronomers had formed this opinion, in spite of their erroneous ideas respecting their relative motions. The cause of her various *phases*, or changing appearances, is very easily understood. Let *s*, in the accompanying diagram, represent the Sun, and *r* the Earth; the outer circle, *a b c d e f g h*, around the latter represents the phases of the Moon, as they appear to us; whilst the inner circle, *i k l m n o p q*, shows her actual state in different parts of her orbit. By this it will be seen, that, whilst that half of the Moon's globe which is turned towards the Sun is always illuminated by him, the portion of the illuminated face presented to the Earth, is continually varying. For, at the conjunction, as seen at *k*, her illuminated side is entirely turned away from us; and consequently, her face is entirely dark, as shown at *a*. But when she has moved

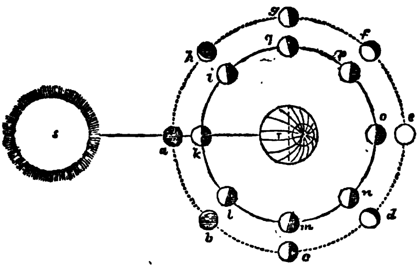

FIG. 175.

to *l*, the edge of her enlightened side is turned towards the Earth, and thus we see the beautiful appearance, shown at *b*, which we term the *new* or *horned* moon,—

> "Dian's bright crescent, like a silver bow
> New strung in heaven."

687. When she has advanced to *m*, half of her illuminated face is then presented to the Earth; and we therefore see her in the state in which she is termed *half* moon, represented at *c*. As she proceeds to *n*, her enlightened face is still more turned towards the Earth; and she gradually becomes *gibbous*, as represented at *d*. And when she has advanced to her opposition, as seen at *o*, the whole of her illuminated face is presented to the Earth, and she is then seen at the *full*, as shown at *e*. During the period of the *waxing*, or increase, of the enlightened surface, the Moon is seen on the east of the Sun, and gradually increases her distance from him, until, at the time of opposition, she rises about the time that he sets, and comes on the meridian about 12 hours after him. The edge over which the illumination is extending, is at this time directed away *from* the sun. The same series of phases is presented to us during the Moon's *waning*, or decrease; but in a contrary order, as shown at *f g h*, until the illuminated face is completely withdrawn. The Moon is then to the west of the Sun, and gradually approaches him, until at last her narrowing crescent disappears in his brightness; its points are then directed *towards* him. When it re-appears on the other side, the whole unillumined face may sometimes be distinguished by its faint copper-coloured light;—an appearance commonly known as "the old Moon in the young moon's arms." This light is reflected from the Earth, which serves as a large and splendid moon to our satellite, and goes through a corresponding series of phases;—with this difference, however, that when the Moon is at full to us, we are invisible to the inhabitants of the Moon, in consequence of our enlightened side being turned entirely away from them; and in like manner, at our new moon, the Earth is at *full* to the inhabitants of our satellite. By a little consideration, it will be seen that all the Earth's phases must be, to the inhabitants of the Moon, just what her's are to us, in the opposite part of her orbit.

CHAPTER XXII.

OF THE NEBULAR HYPOTHESIS.

688. THE question has been already started, whether the peculiar arrangements of our solar system (§. 585), and those of the starry universe in general (Chap. XV.), can be attributed to any one simple principle; or, in other words, whether we can, with a fair degree of probability, assign a common origin to these and trace their subsequent history. The observations of the Astronomer and the reasonings of the Mathematician *do* seem to point to such an explanation; and a brief account of it will be a not inappropriate conclusion to the present volume. But it must be clearly understood that it is at present no more than a probable *hypothesis*,—that is, a theory which serves to explain the phenomena with which we are at present acquainted; but which remains to be confirmed or set aside by the results of further inquiries. We may thus illustrate its nature.—Suppose a person who had never seen or heard of living vegetation, to be placed for a day in the midst of a forest or plantation, and to employ himself in the observation of what he saw around him, and in reasoning from his observations. He would not fail to notice that the objects around him, though manifestly of the same kind, are of different sizes and of various degrees of development; and he might discover all the stages intermediate between the sprouting seed and the majestic tree. Hence he might not be improbably led to the idea of *progressive change;* even though his period of observation were so short, that he could *perceive* none: and he might reasonably arrive at the conclusion, that the objects around him were of a common nature, and that the smaller and humbler would gradually expand themselves into those of larger and more commanding size.

689. Now it has been mentioned (§. 539), that the Astronomer discovers among the almost infinite number of the stars which he surveys, a variety of different appearances; some presenting themselves as points of intense brilliancy; others possessing, round a luminous nucleus, a slight halo of more diffused brightness; others again having this halo more extensive, and the bright nucleus less distinct;—and a regular series being discernible between these, and those patches of diffused luminous matter, in which there is no appearance of any nucleus or tendency to concentration. It has also been mentioned (§. 542) that our own Sun is really accompanied by a luminous atmosphere; although its extent is not sufficient to allow it to be visible from the nearest fixed star; so that we have no right to suppose that even the stars which appear most clearly defined, are really destitute of it. The idea, therefore, cannot be regarded as improbable, that all these masses had their origin in the diffused nebulous matter, some portions of which still remain visible to us; and that their definite form is gradually acquired by the progressive condensation of this, first into a fluid, and then into a solid. Such condensation would be the natural result of the mutual attraction of its particles, and of their common tendency towards the centre of the mass. Now, let it be supposed that this is the real origin of all the solid bodies in the universe, and let the imagination be united with the reasoning powers, in the attempt to ascertain the probable changes, through which any such collection of particles would pass, in their progress towards consolidation;—the actual counterpart or representation of *every one* of these will be found in the sky.

690. It is impossible to imagine a stronger probability, short of absolute proof, than the hypothesis derives from this fact. It cannot be regarded as *proved*, until the observations of astronomers upon the condition of these nebulæ or nebulous stars, shall have shown that a change really takes place. But even though this proof should never be obtained, the hypothesis is not the less probable; for what is the length of man's life—what the duration of all his generations since the commencement of his race, compared with those vast periods of time, which Astronomy

leads us to consider? "Time and change," it has been well remarked, "are great only with reference to the faculties of the beings which note them. The insect of an hour, which flutters during its transient existence in an atmosphere of perfume, would attribute unchanging duration to the beautiful flowers of the cistus, whose petals cover the dewy grass but a few hours after it has received the lifeless body of the gnat. These flowers, could they reflect, might contrast their transitory lives with the prolonged existence of their greener neighbours. The leaves themselves, counting their brief span by the lapse of a few moons, might regard as almost indefinitely extended the duration of the common parent of both leaf and flower. The lives of individual trees are lost in the continued destruction and renovation which take place in forest masses. Forests themselves, starved by the exhaustion of the soil, or consumed by fire, succeed each other in slow gradation. These periods again merge into other and still longer cycles of geological change, which occasions the submersion of the forest, the conversion of its living trunks into their stony resemblances, and the subsequent upheaving of these as portions of the continents and islands of a new surface." In the same manner, "when the birth, the progress, and the history of sidereal systems are considered, we require some other unit of time than even that comprehensive one which astronomy has unfolded to our view. Minute and almost infinitesimal as is the time which comprises the history of our race, compared with that which records the history of our system, the space even of this latter period forms too limited a standard wherewith to measure the footmarks of eternity."*

691. But does this hypothesis, however applicable to the formation of the stars, give an equally satisfactory account of the origin of the planetary system? We do not here see the various stages of the formation still going on; for we know of no planetary system but our own, and its production has been long complete. But the hypothesis, when pursued into its consequences, *does* afford so complete a solution of those peculiarities in the arrange-

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* Babbage, in Ninth Bridgwater Treatise.

ment of our own system, which no other known principle will account for, that we can scarcely hesitate in recognising it as giving us—if not its actual history—at least something very close to it.

692. The first question is,—how a mass of nebulous matter would acquire a rotatory movement. Supposing that it had originally a precisely globular form, all its particles would be attracted towards its centre; and, as they became condensed, their movement would be in straight lines, which would meet from all sides in that one point, so that they would thus all neutralize each others' impulses. But if the mass were of irregular form, its particles would not be all attracted towards the centre with the same force; they would therefore rush towards it with unequal velocities; those on one side would predominate over those of the other; and by the difference, a rotatory movement would be given to the mass,—just as a whirlpool or eddy is produced when two streams of water meet and intermingle. That the flow of matter from all sides should be so nicely balanced, in any case, that the opposite momenta should neutralize each other, and produce a condition of *central rest*, is, in the very nature of things, but a bare possibility. The *probability* that a rotatory movement will necessarily be given to the nebulous mass, in the very commencement of its consolidation, is *almost infinitely greater*. Thus simply do we account for the first great phenomenon of our planetary system,—rotation around a centre.

693. But as the process of condensation goes on, the rotation will become more rapid. This may be understood from the simple consideration, that the particles, which were at first passing through a large circle, are gradually brought, by their nearer approach to the centre, to pass through a smaller one, without any considerable change in their own actual velocity; and that their revolution must therefore be executed in a shorter time. With this increase in rapidity, the centrifugal force will be also augmented; and as there is very little cohesion between the particles of the mass, the centrifugal force of its outer and more rapidly-moving portion, may soon become quite strong enough to overcome this, as well as to surpass the force of attraction towards the centre of the mass. Hence the outer ring

or belt will be thrown off; just as the outer portion of the grindstone separates from the inner, when it acquires a certain velocity (§. 221). As the condensation proceeds, and the rotation of the mass becomes still more rapid, another belt may be detached in like manner; and thus a series of concentric rings may be formed around the central nucleus, each retaining the velocity which the whole mass possessed at the time of its separation, and continuing to revolve about the common centre.

694. Now these rings will themselves share in the tendency to consolidation, by the mutual attraction of the particles of nebulous matter of which they are composed. If they should be precisely equal in thickness in every part, the solid into which they become condensed would retain the form of the ring; but this is a very unlikely occurrence. If one part should be thicker than the rest, *its* centre will be the point towards which all the matter would be attracted; and as they are gradually drawn towards it, their forces, being unequally balanced, will produce a rotatory motion of the mass into which they become condensed, just as in the case first supposed. This mass may itself throw off one or more rings, during its consolidation; and these, on the same principles, may either remain as rings, or may be condensed into globular masses. Further, it is possible that, instead of one predominant centre of attraction, which draws the whole matter of the ring towards it, there may be two, three, or more such centres, having an equal tendency; and thus the ring may become consolidated, not into one globular mass, but into two, three, or more. Whatever ultimate form the ring assumes, the solid mass into which it is converted will continue to revolve around its original centre, with the velocity which it possessed at the time of its separation from the primary mass.

695. Now upon glancing through our own planetary system, we see the precise realisation of these supposed results. For in almost every case, the nebulous ring, thrown off from the primary mass, has consolidated, as might have been predicted, into a single globular mass; and this, during its consolidation, has (in the case of the four largest planets, Jupiter, Saturn, Uranus, and the Earth) thrown off one or more rings, which have become separate

masses, having a motion of their own. The only exception, in the case of the primary planets, is that of the four small bodies revolving between Mars and Jupiter; which, from their near resemblance in size and in distance from the sun, may be considered, with great probability, as having been formed by the breaking up of one ring into four distinct portions, owing to the cause already mentioned. In the same manner, the rings which have been thrown off from the planetary masses during their consolidation, have gradually become condensed into globular bodies, the satellites, which have a revolution round the primaries, as the latter have round the Sun; and these solid masses, from the action of similar causes during their condensation, have a movement of rotation on their own centres. One exception only exists, and this exception is of the highest interest;—the ring of Saturn. We have here an instance of the exact realisation of the most improbable of the three cases supposed in the preceding paragraph. Thus, out of 27 nebulous rings, which (on this hypothesis) have been thrown off from different centres during the formation of our planetary system,—8 of these rings having been thrown off from the primary mass, and 19 from the secondary,—we have *one* instance of the most improbable case, the formation of a solid ring, in the case of a secondary planet; and *one* instance of the case which is but little more probable, the separation of the ring into several distinct masses, occurring in the case of the primary mass; in all other instances, the matter composing the ring has become gradually condensed into a mass of nearly globular form, exactly as theory would predict.

696. There is thus a high probability, that the Sun, together with all the Planets and their Satellites that revolve around him, have had a common origin in a patch of nebulous matter, similar to those which the telescope renders visible to us in the heavens. By such an explanation we can account for the revolution of the planets and their satellites in the same direction, in orbits nearly circular, and having but little inclination to each other,—the conditions neccssary to the general stability of the system (§. 585); and also for the rotation of the sun and of the planets on their own axes. It now remains to be inquired, how

far it accounts for their respective *times* of revolution round the centre. The answer to this question has been given, not long since, by a French mathematician; who calculated, from the known period of rotation of the sun upon his axis, and his known dimensions, what would have been his period, if he had been expanded into a mass extending to the orbit of Mercury; a similar computation was made, for his rate of rotation, supposing his mass to extend to the orbit of Venus;—and so on, for the varying sizes which the nebulous mass must have possessed, at the time that the different rings were thrown off, which have been since themselves consolidated into the planetary bodies. He found that there is a correspondence so very close, between the period in which each planet actually revolves round the sun, and that in which the whole nebular mass was thus estimated to have revolved, at the time when the planetary ring was thrown off, that it is difficult to suppose their motions to have originated in any other way; and a most interesting confirmation was thus given to the general doctrine. Indeed it does not appear that any higher confirmation can be looked for.

697. The nebular hypothesis, then, supposes that there was a time when matter existed in no other form, than that of the diffused self-luminous vapour, of whose existence at the present time we have sufficient evidence; and that, from the simple property of mutual attraction which the particles of this matter possess, its gradual concentration into solid masses commenced; whilst the mode in which this concentration would take place, produce the separation of each into smaller masses, having independent motions of their own. The particular size, number, and movements, of the solid bodies produced in each individual case, must depend upon the size and form of the nebulous mass in which they originated. In our own system, this consolidation must have long been almost complete; we perceive no indications that it is still going on; but it is probable that the luminous atmosphere already described (§. 542) is gradually becoming condensed upon the Sun, and that it is even drawing into itself the comets which revolve around it. The same obstruction which causes them to approach him more nearly in every revolution,

must act also upon the larger masses of our system; and must cause them, in a period of almost infinite length, to be drawn into his sphere,—thus forming a part of the same mass at the period of their greatest condensation, as they did when their particles were most widely diffused.

698. The idea of the nebular hypothesis appears to have been taken up and prosecuted, at nearly the same time, by Sir W. Herschel and by Laplace;—the former, one of the greatest astronomical observers, and the latter one of the most profound mathematicians, that the world has ever seen. In the estimation of the former, it derived its evidence from the various appearances which the heavens revealed to his penetrating gaze, indicating progressive change and formation; whilst in the mind of the latter, it was the result of a train of reasoning of the very highest kind, and would probably have been *to him* little less satisfactory, if no evidence of change and progress had been obtained, provided the complete results accorded, which they have been shown to do. By many persons the nebular hypothesis is looked upon with suspicion, as substituting the idea of a self-existent matter for that of the Great First Cause; and Laplace has been stigmatised as an atheist for the manner (perhaps too unguarded) in which he spoke of the influence of the Deity. But the same charge was brought against Newton, when he developed the application of the great law of gravitation, to explain the movements of the heavenly bodies; and, as we have seen, without the least foundation (§. 576). For, after all, the question arises, —whence the nebulous matter itself—and how did its particles become endowed with the property of mutual attraction? The very fact, that, as we look backwards and forwards, there is still *progressive change*, leads us to perceive, that the present order of things has not existed from all eternity, and that it is not destined to endure for ever. "If we establish by physical proofs, that the first fact which can be traced in the history of the world, is, 'that there was light,' we shall still be led, even by our natural reason, to suppose that, before this could occur, 'God said, Let there be light.'"

699. These views seem to lead towards a generalization much

higher, because more comprehensive, than the principle of gravitation; including with it those other fundamental properties of matter, the actions of which produce the phenomena which we term electrical and chemical, as well as those relating to light and heat. A corresponding simplification is taking place in the science of physiology, or that which embraces the actions of the living beings which people our globe, and which we may reasonably believe to be distributed through every portion of the universe, with such modifications as their circumstances may require; and the progress of science leads to the belief that its upward aims will terminate, in referring *all* the phenomena of the material universe to one simple and universal principle,—the direct expression of the will of the Creator.

700. "If, then, we can conceive that the same Almighty *fiat* which created matter out of nothing, impressed upon it one simple law, which should regulate the association of its masses into systems of almost illimitable extent, controlling their movements, fixing the times of the commencement and cessation of each world, and balancing against each other the perturbing influences to which its own actions give rise,—should be the cause, not only of the general uniformity, but of the particular variety of their conditions, governing the changes in the form and structure of each individual globe, protracted through an existence of countless centuries, and adjusting the alternation of 'seasons and times, and months and years,'—should people all these worlds with living beings of endless diversity of nature, providing for their support, their happiness, their mutual reliance; ordaining their constant decay and succession, not merely as individuals but as races, and adapting them in every minute particular to the conditions of their dwelling,—and should harmonize and blend together all the innumerable multitude of these actions, making their very perturbations sources of new powers;—when our knowledge is sufficiently advanced to comprehend these things, then shall we be led to a far higher and nobler conception of the Divine mind, than we have at present the means of forming. But, even then, how infinitely short of the reality will be any view that our limited comprehension can

attain! seeing, as we ever must in this life, 'as through a glass, darkly;'—how much will remain to be revealed to us in that glorious future, when the light of Truth shall burst upon us in unclouded lustre, but when our mortal vision shall be purified and strengthened, so as to sustain its dazzling brilliancy!" *

701. Of the destiny of Man, in that nobler state of existence to which reason and revelation alike point, we *know* nothing, but have abundant field for most delightful speculation. It is well that every one is left to form his own conception of it; and however elevated that conception, however exalted his imagination, we know that the reality will far transcend it, being such as "eye hath not seen, nor ear heard, nor hath it entered into the heart of man to conceive." As the purest intellectual pleasure of which the mind of man is susceptible in this state of being, is derived from the contemplation of the power and wisdom displayed in the Creator's works,—and as his purest moral happiness is derived from the contemplation of that goodness which is manifested with equal universality and perfection,—we cannot be wrong in the belief that a great part, at least, of the happiness of a future life, shall consist in the more extended survey, which our nobler faculties and our purified feelings will permit us to take, of the grand scheme of Creation, and in the gradual approach towards the perfections of the Creator, which we shall thus be enabled to make. Things which at present appear devoid of expression, shall speak to us of Him; those which we now look upon through the mists of doubt and ignorance, or the darkness of error, shall then present themselves in the effulgence of His glorious brightness; and those which have led our finite understandings to some faint comprehension of His infinite greatness, or which have caused our hearts to expand in the contemplation of His perfect goodness, shall then be regarded by us with a yet deeper and higher interest, as the instruments by which the Creator deigned to lead our minds towards Himself,—the forms in which he clothed those attributes, that our present gross apprehension cannot otherwise receive,—the material types of that spirituality, which, however apparently various

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* Principles of General and Comparative Physiology, §. 745.

in its operations, is One in its essence, and One in its design. To the inspired bard, in ages long gone by, did "the heavens declare the glory of God, and the firmament show forth His handiwork." How much more do they *now* reveal it to the philosopher, who, by the study of their laws, has learned something of His infinite wisdom. How much more *will* they reveal it, when all the barriers that now obstruct the progress of the mind of man shall be removed, and when, instead of a limited existence of "threescore years and ten," *Eternity* shall be the scope of his researches!

——— Open your lips, ye wonderful and fair!
Speak, speak! the mysteries of those living worlds
Unfold!—No language? Everlasting light,
And everlasting silence?—Yet the eye
May read and understand. The hand of God
Has written legibly what man may know,
The Glory of the Maker. There it shines,
Ineffable, unchangeable; and Man,
Bound to the surface of this pigmy globe,
May know and ask no more. In other days,
When death shall give th' encumbered spirit wings,
Its range shall be extended; it shall roam,
Perchance, among those vast mysterious spheres
Shall pass from orb to orb, and dwell in each,
Familiar with its children,—learn their laws,
And share their state, and study and adore
The infinite varieties of bliss
And beauty, by the hand Divine,
Lavished on all its works. Eternity
Shall thus roll on with ever fresh delight;
No pause of pleasure or improvement; world
On world still opening to the instructed mind,
An unexhausted universe, and time
But adding to its glories. While the soul,
Advancing ever to the source of light
And all perfection, lives, adores, and reigns
In cloudless knowledge, purity, and bliss.

Rev. H. Ware.

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